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NUCLEONICS

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FOR TECHNIQUES AND APPLICATIONS OF NUCLEAR SCIENCE

March, 1948

ADMINISTRATION AND OPERATION OF A RADIOCHEMICAL LABORATORY

ELECTRONICS FOR THE NUCLEAR PHYSICIST—II

INVESTIGATION OF REACTION MECHANISMS AND PHOTOSYNTHESIS WITH RADIOCARBON

SELECTION OF RADIOAUTOGRAPHIC TECHNIQUE FOR PROBLEMS IN BIOLOGY

THE SPECIAL THEORY OF RELATIVITY IN NUCLEONICS

NAPHTHALENE COUNTERS FOR BETA AND GAMMA RAYS

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ADMINISTRATION AND OPERATION OF A RADIOCHEMICAL LABORATORY

Contamination and health hazards—among the problems of laboratories handling beta and gamma activities at millicurie level—are discussed as part of the practical aspects for determining design for safe and efficient operation of a "hot" lab

By F. C. HENRIQUES, JR. and A. P. SCHREIBER
Tracerlab, Inc., Boston, Massachusetts

TO AN ORGANIZATION preparing to use radioisotopes, the question of design, operation and administration of a radioactivity laboratory is a major consideration if health hazards and laboratory contamination are to be minimized.

Very little practical information is available on this subject. A number of articles have been written setting forth the experience of experts in radioactivity and enumerating rules for "hot" laboratory operation. Others have been written in extremely broad terms. Invariably these articles have taken the point of view of the AEC laboratories (such as those at Oak Ridge, Los Alamos or Hanford) which handle large amounts of activity including the alpha emitters. The problems in design, operation, and administration of these types of laboratories are not only different but are far more complex than the problems faced by private organizations. Such organizations normally use only beta or gamma emitters in quantities of a much smaller order of magnitude than handled in the AEC-controlled national laboratories.

The data presented in Fig. 1 indicates the order of magnitude of activities required for various classes of radioactive investigations.* This article will be concerned with only beta and gamma activities at the millicurie level. Shielding devices and some remote-control apparatus of a simple nature are required for the laboratories under consideration.

The two major considerations in the design and operation of a "hot" laboratory are contamination and radiation health hazard. Contamination problems are, in general, a function of the half-life of the radioisotope which is involved, while radiation health hazard is dependent upon the amount and energy of the activity present. For example, both sodium-24 (14.8-hr half-life, 1.4-Mev β, 1.4 and 2.8-Mev γ) and potassium-42 (12.4-hr half-life, 75% 3.58-Mev β, 25% 2.07-Mev β, and 1.51 Mev γ) present *substantial* health hazards in millicurie amounts since they emit high-energy beta and gamma radiations but only *minor* contamination hazards since they have short half-lives. On the other hand, when working with high-millicurie strengths of a pure beta emitter with a long half-life (for example, Ca^{45}, 180-day half-life, 0.3-Mev β), the health hazard of external radiation will be small while the contamination hazard is considerable. Thus, it is evident that the relative importance of either of these two factors

* Henri A. Levy, *Chem. Eng. News* **24**, 3168 (1946)

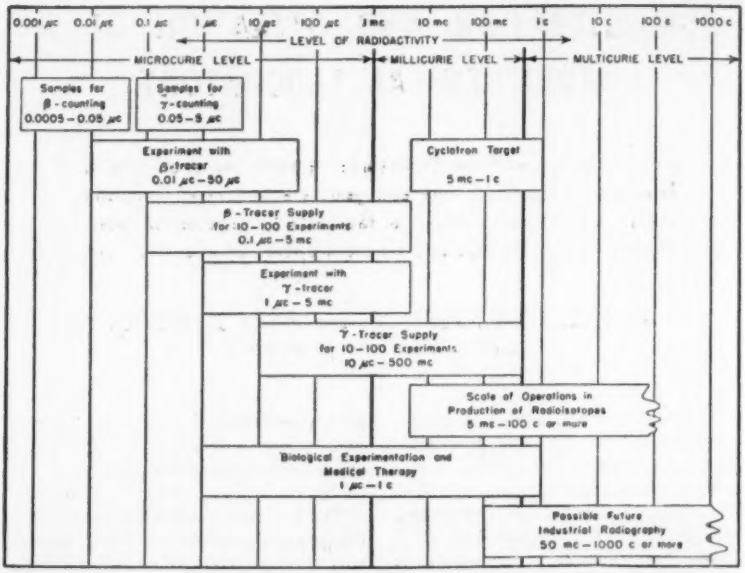
0.001 μc
0.01 μc
0.1 μc
1 μc
10 μc
100 μc
1 mc
10 mc
100 mc
1 c
10 c
100 c
1000 c
LEVEL OF RADIOACTIVITY
MICROCURIE LEVEL
MILLICURIE LEVEL
MULTICURIE LEVEL
Samples for β-counting 0.0005 – 0.05 μc
Samples for γ-counting 0.05 – 5 μc
Experiment with β-tracer 0.01 μc – 50 μc
Cyclotron Target 5 mc – 1 c
β-Tracer Supply for 10 – 100 Experiments 0.1 μc – 5 mc
Experiment with γ-tracer 1 μc – 5 mc
γ-Tracer Supply for 10 – 100 Experiments 10 μc – 500 mc
Scale of Operations in Production of Radioisotopes 5 mc – 100 c or more
Biological Experimentation and Medical Therapy 1 μc – 1 c
Possible Future Industrial Radiography 50 mc – 1000 c or more

FIG. 1. Order of magnitude of activities required for various classes of radioactive investigations.

is to a great extent dependent upon the radioisotopes being handled.

Personnel

The employer bears full responsibility for the well-being of "hot" laboratory workers. As a part of this responsibility all employees should be informed that hazards are involved. Unless an employee is completely willing and feels that adequate safety precautions are being taken, he should not work in a "hot" laboratory.

One of the first and most important administrative rules for a radioactivity laboratory is the delegation of authority and responsibility to one person in the laboratory for the activity stored and in use. Complete records should be kept of persons receiving this activity and of its ultimate disposal. Fig. 2 shows a sample record sheet for this purpose. On it is recorded all shipments received, radioactive materials dispensed, amounts of material on hand at all times, and the initials of the person responsible for receiving or dispensing the activity. Stored activity should always be under lock and key.

In this and other contamination and health matters, it is the man directly in charge of the "hot" laboratory who must be diligent. Approval by a State Department of Health does not guarantee the safety of an installation for handling radioactivity. Frequently, personnel carrying out such inspections lack the broad experience and training necessary to recognize all spots where potential hazards exist. Periodic inspection by representatives of the AEC, while they serve a useful purpose, do not constitute a full guarantee of safety. In such inspections, too, there is a psychological factor to consider. Usually there is advance notice of

RADIOACTIVE MATERIALS RECORD

RADIOISOTOPE I-131 HALF LIFE 8.0 days RADIATION ALPHA ____ Mev. BETA 0.6 Mev. GAMMA 0.37, 0.08 Mev.

DATE	REMARKS	AMT. REC'D	AMT. DISPENSED	BAL. ON HAND	MH/HR AT 1 FT ABOVE OPEN CONTAINER	DESTINATION
12/3/47	In compartment C of safe by J.R.	100 mc. 12 mc/cc.	—	—	120	
12/4/47	Removed by C.M. – Compt. C		25 mc	69 mc.	90	K.L. – Room 211
12/8/47	Removed by J.R. – Compt. C		40 mc.	9 mc.	12	K.L. – Room 211
	Removed by J.R. – Compt. C		1 mc.	9 mc	12	M.F. – Room 322
12/10/47	In Compartment C of safe by C.M.	200 mc. 0.5 mc/cc		206 mc	230	
12/11/47	Removed by C.M – Compt. C		150 mc	56 mc	60	C.M. – Room 211
12/18/47	Removed by J.R – Compt. C		31 mc.	0	0	K.L. – Room 211
12/19/47	In compartment D of safe – J.R.	200 mc 0.8 mc/cc	50 mc.	150 mc	170	J.R – Room 322

FIG. 2. Record sheet for a laboratory using radioisotopes

the inspection and preparations are made so that the inspector sees ideal rather than average working conditions. Further, day-to-day changes within the laboratory will cause corresponding changes in safety of working conditions unless continual watchfulness and care are exercised by all persons working in the laboratory.

Diligence must be exercised in choosing personnel for work in a radioactivity laboratory. One careless worker may endanger the entire laboratory staff and contaminate the laboratory sufficiently to make it useless for further radiochemical work. All but the most cautious workers should be eliminated from participation in "hot" lab work.

Film badges provide excellent indication of careless employees. When one worker continues to show a higher exposure to radiation than the others on the staff, action should be taken immediately, even though radiation dosage may be well below tolerance. Consistently high radiation exposure may indicate a careless worker, in which case a job transfer is in order. If the worker is one who is known to exercise unquestionable caution, on the other hand, then it indicates that he has had an unduly large share of work with high-activity samples and that rotation of "hot" work is in order. Regardless of radiation exposure, it is advisable to rotate personnel working in a "hot" laboratory because of the psychological factors involved. Some workers worry over the possibility of excessive exposure, while others set aside all fear of radiation and become careless. In either case, accident probability is greatly increased.

All personnel working in radioactivity laboratories should know in detail what is expected of them with regard to safety precautions. The best and surest way to making certain that they understand responsibilities is to set down a few simple written rules for them to follow. Frequent checks should then be made by the laboratory administrator to insure that the rules are clearly understood and being obeyed. The type of rules useful for this purpose are given on page 4.

Medical Examination

A complete physical examination should be given to all personnel before their employment in a radioactivity laboratory becomes effective. This

Typical "Hot" Laboratory Rules for Beta and Gamma Emitters

1. No person is to enter "hot" laboratory unless he has a reason to be there. Visitors especially should be limited.
2. Laboratory coats usually worn in the "cold" laboratory shall be removed before entering the "hot" laboratory.
3. All persons working in the "hot" laboratory must wear a laboratory coat, such coat to be kept and worn in "hot" laboratory only.
4. Each person is to monitor bench top, apparatus and material with which he is working before and after completion of the work. Meter readings are to be recorded in the "hot" laboratory notebook. The following tolerance levels of radioactive contamination* should not be exceeded:

Shoes	1000 counts per minute (cpm)†
Laboratory coats and clothing	500 cpm†
Table tops, floors, etc.	300 cpm with counter in contact†
Inside intermittently used hood	4000 cpm†
Smear test on table tops, floors, apparatus, etc. (2 sq in. filter paper smeared over 12 sq in. and counted with β, γ counter)	Zero cpm†
Boxes for shipment by air or mail	Zero cpm with smear test.† Total radiation at outside surface of box in accordance with Interstate Commerce Commission Regulations.‡
All laboratory and operating areas	All areas with radiation greater than 12.5 mr/hr shall be posted.‡

5. Before leaving "hot" laboratory, hands must be monitored and scrupulously cleaned until smear tests yield a reading of zero. Under no circumstances should direct readings on the hands exceed 700 cpm. If it is not possible to reduce the activity to this degree, the Laboratory Director should be informed immediately.
6. No work is to be done on bench tops unless absorbent paper is first laid down.
7. When work is completed, each person is to individually clean and/or dispose of contaminated material.
8. Activity is to be disposed of in waste jars kept in each sink, paper towels disposed of in special containers, etc.
9. The "hot" laboratory is to receive a general clean-up and monitoring every Friday afternoon.
10. All unused activities are to be kept in the "hot" laboratory safe. The removal of any said activity is to be done *only* with the approval of the Laboratory Director.
11. All activities entering or leaving the "hot" laboratory—for shipping, for use in "cold" laboratory, or for any other reason—*must* be monitored and a dated and initialed record entered in the "hot" laboratory log book.
12. There will be *Positively No Smoking, Eating or Drinking* in the "hot" laboratory at any time.
13. Negligence in complying with any of the above rules will result in the employee's dismissal.

* K. Z. Morgan, *Chem. Eng. News* 25, 3794 (1947).
† With thin-window G-M tube.
‡ With ionization chamber meter.

serves the employer as protection against damage claims made by an employee whose ill health or radiation exposure was contracted *prior* to coming into his employ.

A blood smear test is one of the most important parts of the physical examination. If the smear picture deviates significantly from normal, a prospective worker should not be employed for "hot" laboratory work. This is because of the difficulty of determining abnormalities which may occur later. After the initial examination, blood smears should be taken at appropriate intervals to establish the normal pattern of variation. Monthly tests over a period of three to four months should establish this pattern. Following these, quarterly tests are usually sufficient unless overexposure is suspected.

It is essential that the employer have a competent and interested haematologist interpret blood pictures. If any significant blood changes are noted, it may be too late to take preventative action. A blood picture is not a warning of damage ahead but rather a history of damage already done. If a significant change is noted, the employee should be isolated completely from all work involving radioactivity until the physician in charge indicates a return to this type of work is permissible.

Equipment and Laboratory Design

In no instance should radioisotopes be processed in a room used for radioassay work. The reason for this rule is obvious when one considers the orders of magnitude of the activities involved. From Fig. 1 it will be noted that 10^{-4} microcuries or less are required for counting. It is sometimes necessary to handle or process as much as a billion times this amount of activity. In view of this, it is usually impossible to prevent contamination unless three physically isolated rooms are provided for radioactivity work namely, (a) the microcurie level where radioassay work is done, (b) the intermediate level where experimentation takes place, and (c) the millicurie level where radioisotopes are stored and processed. There will be some instances where three separate rooms will not be absolutely necessary, but at least two separate rooms should be considered as essential.

There must be no easy and direct access to or between the counting room and the "hot" laboratory. Equipment used in a "hot" laboratory should never be used elsewhere. Except for personnel and the finished product, there should be one-way traffic for everything entering such a laboratory. Contamination is the main reason for such a rule. If low-activity tracer or animal work is done elsewhere on the premises, interchange of equipment undoubtedly would cause erroneous results in the experiments.

There are two schools of thought on the matter of construction materials for laboratory working surfaces. Some laboratories use stainless steel, which after contamination can be washed off with water or acid; others prefer a porous material such as Masonite or Transite which is discarded when contaminated. The problem of radioactive dust from evaporation and crystallization of radioactive solutions may be serious with stainless steel surfaces. Porous bench tops, however, do not present this difficulty. It is necessary to balance this disadvantage of stainless steel against the trouble of periodically removing contaminated bench tops.

The possibility of contaminating the laboratory with sufficient activity to warrant major reconstruction always exists. The importance of removability and disposability of major pieces of fixed equipment, such as benches and hoods, should therefore not be overlooked. It is usually not difficult

to remove and replace such equipment if the construction is simple and composed of inexpensive materials.

Whenever possible it is advisable to work in a well-ventilated hood to prevent gas and spray from contaminating the worker or the laboratory. The hood table should slant inward to localize contamination caused by breakage and spillage. Absorbent paper with a nonabsorbent backing should be used for all working areas to prevent the spread of activity. This paper should be monitored periodically and replaced when excessive activity is found present.

Even though the materials may be in a well-ventilated hood, it is advisable to wear a respirator when handling volatile or gaseous radioisotopes. In the case of carbon-14 in carbon dioxide or in certain volatile organic compounds, appreciable quantities of which may be absorbed by the body with severe consequence, this precaution is particularly important.

To prevent contamination of the hands if spilling occurs, rubber gloves, preferably the thin surgical type, should always be worn when handling activity samples. When contaminated, gloves should be thrown away. Lead-lined gloves have been considered many times but it appears that their disadvantages far outweigh any protection they may give. In many instances secondary radiation from the lead causes greater roentgen dosage than the primary radiations. Since they are awkward to work in, they tend to increase the likelihood of spillage. In instances where the cited disadvantages do not hold, other means, such as the use of tongs or other remote-control instruments, are to be preferred.

FIG. 3. Tools for remote handling of radioisotopes

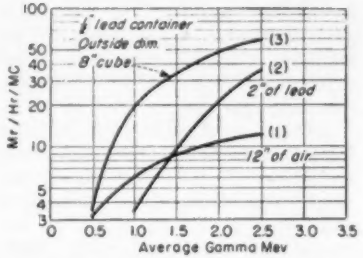

FIG. 4. Comparison of lead shielding and distance for radiation protection:

(1) Roentgen dosage from unshielded point sources at a distance of 12 inches in air.

(2) Roentgen dosage from point sources shielded by 2 inches of lead, with the activity resting on the lead shield and measurements taken at the surface of the opposite face of the shield.

(3) Roentgen dosage from point sources at the center of a container in the form of an 8-inch cube shielded with ½ inch of lead with measurements taken at an outside face of the container.

(In this case MC denotes a gamma-ray flux of 37×10^6 quanta per sec)

The use of remote handling tools is essential with samples of high activity. These tools keep the activity at such a distance as to minimize the resulting roentgen dosage. They should be designed to minimize the possibility of breakage and spillage of the radioactivity container. If too long, these tools are cumbersome. The maximum practical length is approximately two feet. Radiation exposure is lowered by a large factor if the distance of the sample from the body is considered as two feet plus length of operator's arm.

Both the three-finger and the V-shaped are desirable types of gripping mechanism. It is important that the grip remain closed after pressure is

once applied. Remote handling tools should be made of stainless steel to permit decontamination and the grip should be covered with removable absorbent material such as asbestos. These tools should be available in a large number of sizes or be sufficiently adaptable to handle a wide range of sample-container diameters. The safest type of handling tool is one in which the sample is held within a metal container that is an integral part of the remote handling tool. Unfortunately this type of tool is not adaptable to all laboratory work. It is highly recommended, however, if the work is of sufficiently routine nature to warrant the design of a special tool.

Up to now, no really satisfactory remote handling tools are commercially available. There is a great need for such tools and it is understood that this need will be met in the near future with a variety of remote handling tools especially designed for use in radioactivity. Fig. 3 shows several such tools of the type designed and used in laboratories of the AEC.

The importance of distance as a protection from radiation hazards should not be underestimated. An example will show how effective remote handling tools may be. Two inches of lead will lower roentgen dosage rate of a flux of 1.0 Mev gamma rays to 4 milliroentgens per hour per equivalent millicurie. This is based on the assumption that the activity is resting on the lead shield, that it is a point source, and that measurements are taken at the surface of the opposite face of the shield. To achieve the same roentgen dosage rate per millicurie for the same sample without shielding of any sort, it is only necessary to have 14.5 inches of air without intervening shielding between the radioactive source and the point at which it is desired to have a dosage of 4 mr/hr/equivalent mc. Fig. 4 shows additional data on comparisons of lead

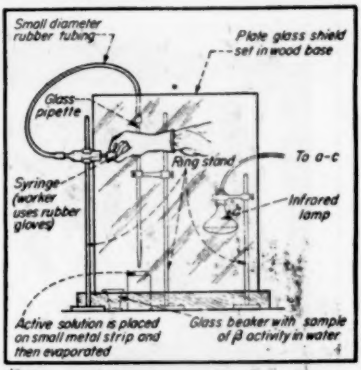
Small diameter rubber tubing
Plate glass shield set in wood base
Glass pipette
Ring stand
To a-c
Syringe (worker uses rubber gloves)
Infrared lamp
Active solution is placed on small metal strip and then evaporated
Glass beaker with sample of β activity in water

FIG. 5. A remote-control pipetting apparatus for handling solutions containing beta activity

shielding and distance for radiation protection.

Special Techniques

No radioactivity experimentation should be carried out until dummy runs, complete in every detail, are made with nonradioactive materials. Such runs should be repeated until the entire procedure is completely reproducible. If an improvement is conceived, then a complete dummy run incorporating the improvement should be made. Even though it is intended to reduce accidents, personnel and contamination hazards and loss of the valuable materials involved, this rule is probably broken more than any other one.

Means for processing isotopes by remote control are essential to prevent exposure of operating personnel. A little ingenuity in using the materials and equipment commonly available in a chemical laboratory will usually solve the problem of remote-control apparatus. For example, a very simple remote-control pipetting apparatus is shown in Fig. 5. This particular setup is designed to pipet a measured quantity of liquid containing a beta emitter and flow it on a small metal strip. The strip

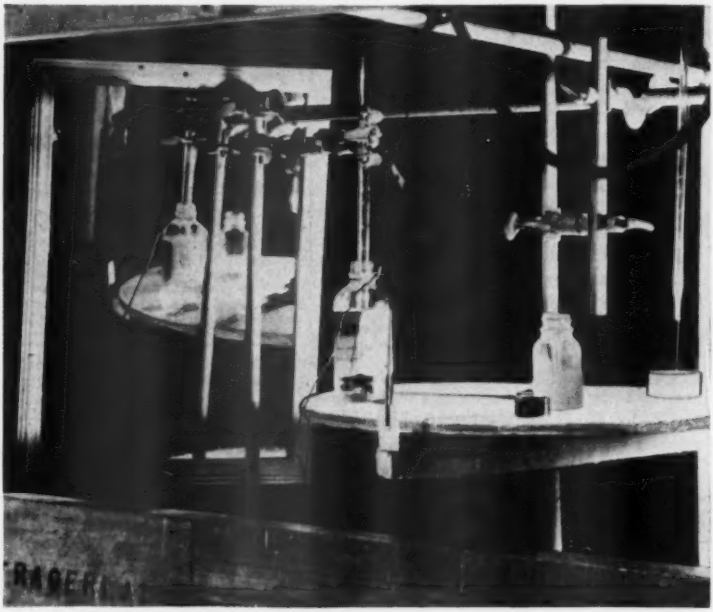

FIG. 6. A simple turntable for carrying out remote-control processing of radioisotopes; the lead brick wall has been partially removed to show the details of the turntable and a mirror which facilitates manipulations

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A preparation in which the remote-controlled shielded turntable can be used is described below.

Preparation of Sodium-24 Azide to be used in the preparation of metallic sodium-24: Conversion of sodium carbonate to sodium azide followed by its decomposition to sodium metal according to the following reactions:

$$Na_2CO_3 + Ba(OH)_2 \rightarrow NaOH + BaCO_3$$
$$NaOH + N_2H_4 \cdot H_2O + C_4H_9NO_2 \rightarrow NaN_3 + C_4H_9OH + 3H_2O$$
$$2NaN_3 \rightarrow 2Na + 3N_2$$

Starting Material: Oak Ridge irradiation unit containing 0.3 g Na_2CO_3 as target material and 20 millicuries of activity as Na^{24} (14.8-hr half-life, 1.4-Mev β, 1.4 and 2.8-Mev γ).

Turntable Setup: Turntable rotates and is capable of vertical motion. Items of equipment in fixed positions with respect to the turntable are: Position 1—remote-controlled pipette containing distilled water; Position 2—infrared lamp with small glass tube connected to nitrogen tank; Position 3—burette containing absolute ethyl alcohol; Position 4—reflux condenser in the top of which has been placed a burette containing butyl nitrite solution; Position 5—small centrifuge tube surrounded by an ice-salt bath.

Equipment on Turntable: (*a*) one empty 25-cc beaker; (*b*) beaker containing saturated $Ba(OH)_2$ solution; (*c*) empty 25-cc beaker; (*d*) 25-cc round-bottom flask provided with a ground joint and containing hydrazine sulfate (flask is surrounded by heating mantle); (*e*) beaker containing 50-50 mixture of alcohol-ether.

Procedure:

1) All steps described below previously carried out in complete detail with nonradioactive Na_2CO_3. The quantity of material involved is a scaledown of the published procedure.*
2) Irradiation unit is opened and, with a long-handled tool, the irradiated sodium carbonate is poured into beaker (*a*) on the turntable.
3) Beaker is rotated to Position 1, and distilled water in pipette discharged into beaker; beaker (*a*) is then turned to Position 2 to allow warming and occasionally swirled, by means of long-handled tongs, to promote dissolution.
4) Turntable is rotated to allow pipette in Position 1 to be filled with saturated $Ba(OH)_2$ solution in beaker (*b*). Table is then rotated for discharge of $Ba(OH)_2$ solution into beaker (*a*).
5) Resulting barium carbonate is allowed to settle. Turntable is vertically adjusted to permit the pipette (Position 1) to be used to remove the mother liquor in beaker (*a*).
6) Mother liquor is transferred to empty beaker (*c*) and this beaker turned to Position 2 where the solution is evaporated to dryness under an infrared lamp. A stream of nitrogen through the attached tube is played over the solution to prevent reaction with CO_2 in the air during the drying process.
7) Beaker (*c*) containing the dried residue (NaOH) is turned to Position 3 under a burette containing a predetermined amount of absolute ethyl alcohol. The stopcock of the burette is turned to open position with a pair of long-handled tongs.
8) Beaker is returned to Position 2 where it is warmed under the infrared lamp and slowly swirled, by means of long-handled tongs, until the sodium hydroxide has dissolved in the alcohol.
9) After residue is allowed to settle, beaker is rotated back to Position 1 where the remotely controlled pipette is used to transfer the liquid from the beaker to the 25-cc round-bottom flask (*d*).
10) Turntable is rotated to Position 4 and raised to allow flask (*d*) to join reflux condenser. Heating mantle is turned on and the mixture heated to 100° C; then the heat is turned off. By means of long-handled tongs, stopcock on the burette (Position 4) is opened and the solution is added at a rate sufficient to continue a gentle refluxing. After all the butyl nitrite has been allowed to run into flask through the top of reflux condenser, heating mantle is turned on once more for ten minutes to complete the reaction. Heating mantle is then turned off. Turntable is lowered to allow detaching of flask from condenser with the aid of long tongs. Heating mantle is turned on and the liquid evaporated to one-half volume.
11) Turntable is rotated to Position 1 and solution in flask (*d*) is drawn up into pipette. Table is then rotated to Position 5 and solution dispensed into centrifuge tube chilled in ice-salt bath to precipitate sodium azide.
12) By means of long-handled tongs, tube is removed from cold bath and placed in centrifuge adjoining turntable. Following centrifugation, centrifuge tube is placed in cold bath again.
13) Mother liquor removed by means of pipette (Position 1) and azide precipitate washed twice by repeating **11** and **12** with a 50-50 mixture of alcohol-ether (*e*).
14) With long-handled tongs, a centrifuge tube is placed in heating mantle and final traces of alcohol and ether are removed by gentle warming.
15) Metallic sodium is prepared by attaching centrifuge tube to vacuum apparatus and decomposing azide by heating to 300° C.

* "Inorganic Synthesis," Vol. II, p. 139, W. C. Fernelius, Editor-in-Chief (McGraw-Hill Book Co., Inc., New York, 1946)

is then placed under an infrared lamp to evaporate the liquid and deposit the activity evenly. Since the radioisotope used on the strip is a pure beta emitter, a plate-glass shield is sufficient to prevent radiation exposure of the worker. The remote transfer burette which obviates the need for pipetting by mouth consists of a hypodermic syringe attached by rubber tubing to a standard pipette. For obvious reasons any transfer involving radioactive liquids, however small in quantity, should never be made by mouth as in ordinary pipetting. Simple instruments such as described can easily be devised to eliminate this hazard to personnel.

If weighing of radioactive materials is required, the balance should be kept in a hood and a metal extension placed on the balance beam release handle. It is sometimes necessary to use lead bricks to lower the gamma radiation dosage of the operator. If beta activity is used, the glass case of the balance is sufficient protection.

Frequently the process of weighing powder is difficult because of the danger of contamination and excessive radiation exposure. In some instances it is advisable to dissolve a solid in an appropriate solvent, withdraw an aliquot sample through a remote control pipette, discharge it into a pre-weighed container, evaporate it under an infrared lamp, and then weigh it. This procedure permits the use of remote-control techniques in transferring and handling which would otherwise be impossible if the material were in solid form.

A remote-control turntable should be considered almost a necessity for laboratories processing millicurie amounts of gamma emitters. Fig. 6 shows a photograph of a simple turntable on which all but the most complex kinds of processing can be performed. A lead brick wall used for shielding has been partially removed to show the details of the turntable and the mirror which facilitates manipulations when the brick wall is in place. The turntable, which is mounted in a laboratory hood, can be rotated on its axis or raised or lowered by simple counterweights and cords manipulated from outside of the lead barrier. Provisions are made for clamping standard pieces of laboratory equipment (pipettes, burettes, small heating coils, refluxing condensers, infrared lamps, etc.) above the turntable so that the radioisotopes can be successively processed with the appropriate equipment. A typical series of processing steps in which a turntable can be used is described below the photograph.

All rules of procedure should be tempered with common sense. For example, it is usually advisable to allow localized exposure of the hands covered with rubber gloves to 4 to 5 times tolerance dosage for a short period of time rather than to expose the entire body to tolerance dosage over a much longer period. This is particularly true where the alternative is a slow, painstaking procedure.

Radioactivity Surveying and Monitoring

The operating head of a laboratory using radioactivity is confronted with three distinct types of radiation surveying and monitoring problems. First, there is need for a complete and continuous record of radiation exposure of laboratory personnel. Second, there is the problem of measuring radiation of the order of magnitude of tolerance dosage or greater to spot-check potential health hazards. Third, it is important that radioactivity contamination of a low order of magnitude be checked both for protection from ingestion and assurance of reproducibility of experimental work. To make the proper decision on each of these problems, it is essential that the person responsible have at least an elementary knowledge of radiation dosage and its measurement, the types of radiation measuring instru-

ments commercially available, and the advantages and limitations of each type.

Health Monitoring

Probably the most satisfactory means for continuous personnel monitoring is the film badge which gives an indication of the total amount of exposure over a given period of time such as a week. The film badge should, in general, be worn on the chest since this spot gives as accurate an indication of over-all body radiation as it is possible to get. Radiation sufficient to produce irreversible pathological alterations in the hands will usually produce indications of radiation dosages significantly above tolerance on film badges worn on the chest. Unfortunately film badge rings have not been developed to a sufficient degree of reliability to warrant serious consideration.

In theory, minometers or pocket dosimeters will give the same answer; in practice, however, they are not as satisfactory as the film badge. When discharged, they give false readings. Dropping and high humidity are among the many ways in which discharge can occur. An extremely high reading always presents the uncertainty of whether excessive exposure or accidental discharge has caused it. To minimize this uncertainty, AEC laboratory personnel usually wear pocket dosimeters in pairs together with a film badge.

With a pocket dosimeter, the possibility of human error in an exposure reading that cannot be rechecked at a later date is always present. Its advantage, however, is that it can be read daily. Reading of film badges, on the other hand, are not ordinarily made more often than once a week, but their advantage is that they provide a permanant record which can be referred to in the event of legal difficulties and verified at any time. To insure completely reproducible and reliable results with the film badge, it is, of course, assumed that qualified personnel using good techniques and procedures will process the exposed films.

The film badge is a satisfactory radiation dosage monitor for gamma rays with energies greater than 0.05 Mev, for neutrons when a cadmium filter is used, and for all but the low-energy beta emitters such as C^{14} and S^{35}. Fortunately in the case of C^{14} and S^{35} the energies of the beta rays are such that practically all of the radiation impinging upon the skin is completely absorbed in the dead layers of the epidermis. The relatively thick plastic and/or metallic walls of the dosimeter make it useful only for gamma radiation. This is a significant disadvantage since nearly all radioisotopes emit beta radiation.

These monitors all give an indication of what *has* happened rather than what *is* happening during exposure. It is quite essential that every laboratory with more than microcurie quantities of activity on hand have a means of checking radiation exposure at each stage of every experiment.

ICC Regulations

All radioisotope storage containers should be monitored to make certain that they are sufficiently well shielded. No more than 10 milliroentgens per day should be read on an ionization-type survey meter contiguous to any laboratory storage container. Recently the Interstate Commerce Commission promulgated regulations for controlling shipment of radioactive materials. An abstract of the most pertinent points of these regulations is given on page 13. They are intended merely as a guide and not as a full interpretation of the regulations. The reader is referred to the Federal Register, Vol. 12, No. 220, pages 7329–7333 for the full text. Fig. 7 shows the type of labels required

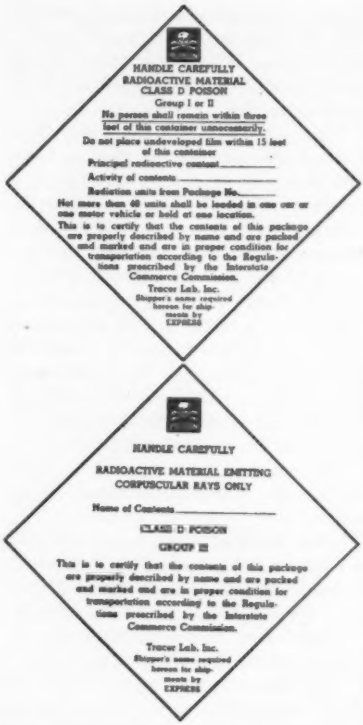
HANDLE CAREFULLY
RADIOACTIVE MATERIAL
CLASS D POISON
Group I or II
No person shall remain within three feet of this container unnecessarily.
Do not place undeveloped film within 15 feet of this container
Principal radioactive content
Activity of contents
Radiation units from Package No.
Not more than 40 units shall be loaded in one car or one motor vehicle or held at one location.
This is to certify that the contents of this package are properly described by name and are packed and marked and are in proper condition for transportation according to the Regulations prescribed by the Interstate Commerce Commission.
Tracer Lab. Inc.
Shipper's name required hereon for shipments by EXPRESS
HANDLE CAREFULLY
RADIOACTIVE MATERIAL EMITTING CORPUSCULAR RAYS ONLY
Name of Contents
CLASS D POISON
GROUP III
This is to certify that the contents of this package are properly described by name and are packed and marked and are in proper condition for transportation according to the Regulations prescribed by the Interstate Commerce Commission.
Tracer Lab. Inc.
Shipper's name required hereon for shipments by EXPRESS

FIG. 7. In accordance with recent Interstate Commerce Regulations, shipping containers for radioisotopes must carry labels such as these

on shipments of radioactive material that fall under these regulations.

Any employer using radioisotopes emitting gamma or greater than 0.2-Mev beta rays has need for a roentgen dosage meter. Further, he is not carrying out his obligations to his employees unless an ionization-chamber meter is used since only this type of instrument gives a reasonably accurate indication of roentgen dosage over a wide range of both beta and gamma energies.

The Geiger-Müller tube indicates the presence of each discrete particle which enters and produces ionization in its sensitive volume. Once ionization is produced, no discrimination is made between alpha, beta, or gamma radiation, nor is any indication given of the magnitude of the energy of the radiation. In view of the wide variations in sensitivity to both gamma and beta rays as a function of energy, the Geiger-Müller tube is basically unsatisfactory for use as a general-purpose roentgen dosage meter. In fact, it is a misnomer to call any such instrument a roentgen dosage meter.

The ionization chamber does not distinguish between individual particles but rather gives an indication of the ionizing quality per unit path length of the radiation it intercepts. In roentgen dosage measurements, it is the measurement of total ionizing ability of the radiation rather than the indication of its emission rate that is important. The ionizing ability plus penetrating ability are factors which determine the potential health hazard that exists from a source of radiation. In the case of ionization chamber type roentgen dosage meters, the penetrability of the radiation is approximated to the first degree through the use of standard filters.

An ionization chamber type of roentgen dosage meter should be used in any instance where the order of magnitude of exposure is in the tolerance dosage range. Such a meter should be available at all times to the radioactivity worker to permit him to check the amount of exposure he is receiving and take appropriate steps quickly to lower it by lead shielding for gamma and thick plastic or glass sheets for beta radiation. Immediately after opening a lead safe containing radioisotopes, the radiation survey meter should be used to determine the amount of activity present. In this way, the proper shielding can be constructed around the experimental setup which will receive

Excerpts from Regulations Governing Shipment of Radioactive Materials

Radioactive Materials:

Group I. Radioactive materials that emit gamma rays only or gamma rays and alpha and/or beta rays.

Group II. Radioactive materials that emit neutrons only or neutrons and alpha, beta and/or gamma rays.

Group III. Radioactive materials that emit alpha or beta rays only.

Packaging and Shielding Requirements:

(*a*) **Radium, plutonium or strontium** must be packed in an inner metal container of stainless steel, malleable iron or brass, not more than 3 in. in diameter or 8 in. in length, minimum wall thickness $\frac{1}{8}$ in. and having screw closure.

(*b*) **Fogging of undeveloped film** at 15 ft for 24 hr must not exceed that produced by 11.5 mr of gamma rays of radium filtered by $\frac{1}{2}$ in. of lead.

(*c*) **Minimum dimensions** of outside container is 4 in.

(*d*) **Outside container** must be of such design that gamma radiation will not exceed 200 mr/hr at surface.

(*e*) **Group I** radioactive materials must be so packed and shielded that gamma radiation at one meter (39.3 in.) from radioactive source does not exceed 10 mr/hr.

(*f*) **Group III** radioactive materials must be so shielded and packed as to prevent the escape of primary alpha or beta radiation, and secondary radiation at the surface of the package must not exceed 0.4 mr/hr (10 mr/24 hr).

(*g*) **Liquid** radioactive materials must be surrounded by absorbent material which will completely absorb liquid in case of breakage. Materials packed in metal tube do not require absorbent packing.

Labels:

(*a*) Each outside container of Group I or II radioactive materials must carry the special red on white label with certification.

(*b*) Each outside container of Group III radioactive materials must carry the special blue on white label with certification.

Exemptions:

Radioactive material that meets all of the following conditions is exempt from prescribed packaging, marking and labeling requirements:

(*a*) Package must be such that there can be no leakage during normal transportation.

(*b*) Package must contain not more than:
(1) 0.1 mc of radium or polonium
(2) That amount of Sr^{89}, Sr^{90} or Ba^{140} which disintegrates at a rate of more than 5×10^6 atoms/sec (0.13 mc).
(3) That amount of any other radioactive substance which disintegrates at a rate of more than 50×10^6 atoms/sec (1.3 mc).

(*c*) Package must be such that no significant alpha, beta or neutron radiation is emitted at the surface of the package and the gamma radiation at any surface must be less than 0.4 mr/hr (10 mr/24 hr).

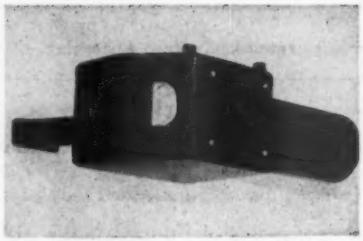

FIG. 8. An ionization-chamber type of radiation survey meter initially designed for use on the Manhattan Project

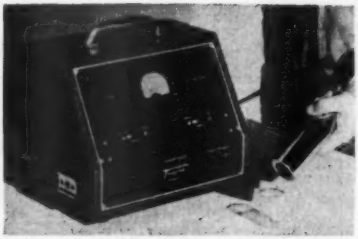

FIG. 9. A Geiger-Müller tube counting rate meter used to monitor residual activity present on a beaker

the activity. Fig. 8 shows an ionization chamber type of radiation survey meter, initially designed for use on the Manhattan Project

Contamination Monitoring

Personnel should be monitored whenever leaving a "hot" laboratory. Of most vital concern is contamination of the hands. This is important not so much for health protection as for preventing contamination of tracer experiment work in "cold" laboratories which may be situated nearby. When handling certain long-life isotopes which tend to remain in the body (C^{14} or Sr^{90}, for instance) even small quantities on the hands may be dangerous because of possible ingestion. Laboratory coats should never be taken from the "hot" lab but should be monitored periodically and discarded when activity becomes appreciable.

It is extremely important that routine general monitoring of all equipment take place when different isotopes are being used. The reason for this is quite apparent. If an experiment is done with what is believed to be a pure radioisotope, and minute amounts of another isotope with significantly different chemical characteristics happens to be present, the tracing characteristics of the major isotope may be impaired by the contaminating isotope. This is due to the fact that it may concentrate in a different part of the system under study and give erroneous results. If only a single radioisotope is used in the laboratory, then, unless the level of contamination is significant, no more than ordinary care is required. Since most laboratories handle several radioisotopes, it should be a part of normal laboratory routine to monitor all equipment before starting any new experiments.

If contamination is found, the equipment should be cleaned by subjecting it to acidic or basic solution concentrations similar to those to be encountered in the experimental work. If significant amounts of the radioisotope continue to cause difficulty, the equipment should be discarded or stored until the contaminant, if it has a short half-life, has decayed to a negligible value.

The residual amount of contaminating activity on equipment, bench tops, fingertips, etc., is always of a much lower order of magnitude than can be measured by an ionization chamber type radiation survey meter. (See the *"Hot" Laboratory Rules* on page 4.) Frequently it is necessary to detect less than a hundred counts per minute. Thus, it is evident that a sensitive instrument is needed. The best type for such monitoring work is a counting rate meter having a thin-mica-window G-M tube. It makes possible a quick survey of amounts of contaminating

activity. Also, the thin window tube permits detection of low-energy beta emitters such as C^{14} and S^{35}. Fig. 9 shows such an instrument being used to monitor the residual activity present on a beaker. Of course it is possible to use a scaler as a laboratory monitoring device but it lacks the convenience of portability and ease of reading obtainable with a counting rate meter.

Although it is apparent that many precautions must be taken, radioisotope work is fundamentally no more hazardous than work involving poisonous materials or high voltage. The greatest limitation has been, and for some time will continue to be, the lack of qualified personnel to direct the safe and efficient operation of radiochemical laboratories.

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ELECTRONICS FOR THE NUCLEAR PHYSICIST—II

In this second of three articles on fast electronic circuits, the author discusses signal-to-noise ratio of counter amplifiers, design of pulse amplifiers, transient analysis of a 2-stage feedback amplifier, and discriminators and scaling circuits

By W. C. ELMORE
Swarthmore College, Swarthmore, Pennsylvania

THE FIRST ARTICLE of this series (published last month) contained discussions of the method of the Laplace transformation (Sec. I), the response of various circuit elements to a step function (Sec. II), and the theory of the transient response of voltage amplifiers (Sec. III).

IV. Signal-to-noise Ratio of Amplifiers Used in Counting Applications

1. The Signal. In most of the subsequent analysis, it is assumed that the signal consists in the sudden appearance of an amount of charge Q_s on the capacitance C associated with the input grid of the amplifier. The capacitance C includes that of the electrical detector, of connecting leads and of the input grid. It can be shown that, to a very good approximation, any alteration of the effective input capacitance by feedback affects signal and noise alike. For this reason it suffices to consider the case where the value of C has no contribution from feedback arrangements. The charge Q_s evidently produces a step in voltage at the input grid. The rise time of the step is assumed to be short compared with the rise time of the amplifier. If this is not the case, a lower signal-to-noise ratio than the one to be computed will result.

The output signal of the amplifier (which includes noise as well as the signal from Q_s) is usually examined to discover the number of voltage peaks (pulses) per second, often as a function of pulse height. Evidently the amplifier should be designed with the express purpose of converting voltage steps into pulses of a desired duration, and, if possible, of a shape most suitable for counting. The pulse shape and duration, of course, affect the signal-to-noise ratio. The method used most commonly for shaping pulses is to include a single, short-time-constant coupling network in the amplifier. (See Sec. V and XI.)

2. Noise. The following list of electrical noises arising in amplifiers is divided into two parts; the first includes noises which can be eliminated by proper design and care in installation of the amplifier, and the second, noises which set the ultimate signal-to-noise ratio which can be achieved with a pulse amplifier used for detecting small charges.

1. Hum
   Microphonics
   Extraneous transients picked up
   Noise from defective components
2. Resistor noise
   Grid-current noise
   Shot-effect noise
   (Flicker effect noise—important only at very low frequencies)

Some of the noises of the first sort usually cause trouble in a practical set-up, especially when low counting rates are necessary. Here we shall assume

utopia and concentrate on noises of the second sort, omitting any consideration of noise from the flicker effect, which is important only in amplifiers designed to have an appreciable amplification at very low frequencies.

Since the signal in which we are interested consists of the charge collected on the capacitance C, it is convenient to refer all sources of noise to an equivalent rms noise charge Q_n, which if placed on C, produces the same noise voltage at the output of the amplifier that the actual sources of noise produce. Our first task, therefore, is to convert the well-known expressions for noise, stated in terms of rms noise voltage, into expressions for the equivalent rms noise charge occurring on the capacitance C. In all cases, small letters squared (for voltage, current or charge) will refer to the mean square value in unit frequency (ordinary, not angular) range (4).

A. Resistor Noise. Thermal agitation of electrons in a resistor causes a voltage (see Fig. 14) to appear across its open-circuited terminals.

$$v'^2_R = 4kTR \quad \text{(Basic relation)} \qquad (29)$$

We are primarily interested in the

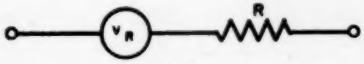

FIG. 14

case where R is shunted by a capacitance C. To find the equivalent rms noise charge on the capacitance which will give the noise voltage required by Eq. (29), we make the two transformations shown in Figs. (15) and (16). From the first of these transformations, we find that

$$v'^2_R = 4kTR_{eff} \qquad (29a)$$

where

$$R_{eff} = \frac{R}{1 + \omega^2R^2C^2} = \text{real part of impedance } Z = \frac{R}{1 + j\omega RC}$$

Then by means of the second transformation, we find that

$$q_R^2 = \frac{4kT}{\omega^2 R} \qquad (30)$$

It must be emphasized that Eq. (30) is simply an alternative form of Eq. (29), derived by simple circuit analysis. It is interesting to note that the capacitance C does not occur explicitly in Eq. (30).

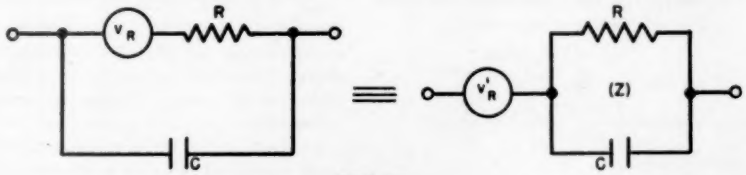

FIG. 15

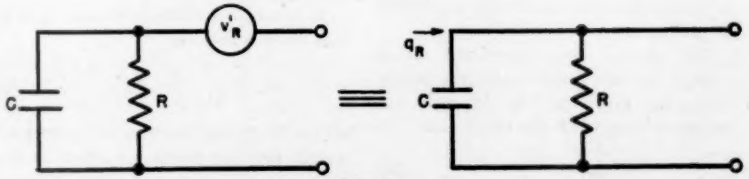

FIG. 16

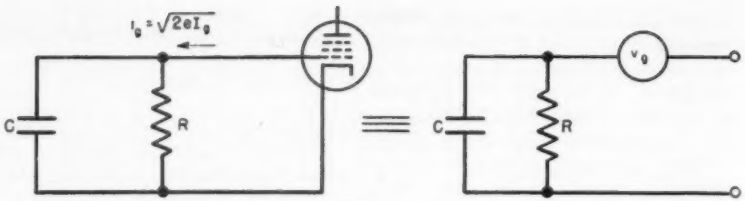

FIG. 17

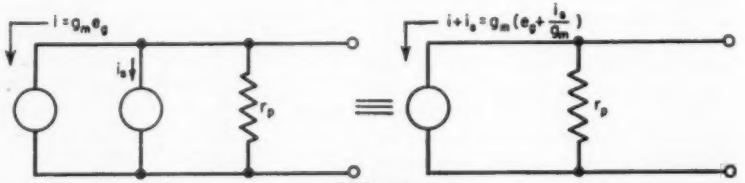

FIG. 18

B. Grid-current Noise. The basic noise phenomenon regarding grid current is caused by statistical fluctuations in the arrival of ions at the grid. The mean square noise current (in unit frequency range) is

$$i_n^2 = 2eI_g \text{ (Basic relation)} \quad (31)$$

where I_g is the sum, without regard to sign, of the positive and negative components of grid current reaching the grid. When the impedance in the grid circuit consists of an R and C in parallel, we can make the transformation given in Fig. 17 leading to the relation

$$v_g^2 = 2eI_g \mathrm{R}\mathrm{R}_{eff}.$$

If we now use Eq. (29*a*),

$$v_g^2 = \left(\frac{2eI_g\mathrm{R}}{4kT}\right) v'_R{}^2 = \frac{R}{\mathrm{R}_g} v'_R{}^2$$

where

$$\mathrm{R}_g \equiv \frac{4kT}{2eI_g} \quad (32)$$

is termed the equivalent noise resistance of grid current.

To obtain the equivalent noise charge, we can again make the transformation given in Fig. 16, with v_R' replaced by v_g, with the result that

$$q_g^2 = \frac{4kT}{\omega^2 \mathrm{R}_g}. \quad (33)$$

Equation (33) is identical in form to Eq. (30), with the physical resistance R replaced by a ficticious equivalent noise resistance R_g. For purposes of computation, the two resistances may be considered as in parallel.

C. Shot-effect Noise. Shot-effect noise is caused by statistical fluctuations in the plate current of a vacuum tube due to the finite charge on the electron. The mean square plate noise current due to this effect is

$$i_s^2 = \eta \cdot 2eI_p \text{ (Basic relation)} \quad (34)$$

where η is a factor ($\eta \leq 1$) arising from a suppression of the effect by space charge. Equivalent circuits for a tube including this source of noise are given in Fig. 18.

Evidently i_s/g_m is the rms equivalent noise voltage at the grid producing the same fluctuation in plate current as the shot effect.

It is customary to define an equivalent noise resistance

$$\mathrm{R}_s \equiv \frac{1}{4kT}\frac{i_s^2}{g_m^2} = \frac{\eta \cdot 2eI_p}{4kTg_m^2} \quad (35)$$

which, if placed in series with the grid, would produce the same effect in the plate circuit as the shot effect. Values

of R_s range from a few hundred to a few thousand ohms, depending on tube type. Finally, we make the transformation shown in Fig. 19 in order to find the equivalent noise charge due to the shot effect. By simple circuit analysis we find that

$$q_s^2 = 4kTR_sC^2. \qquad (36)$$

Evidently it is important to have R_sC^2 small as possible to minimize this source of noise. Hence the quantity $g_m/C_{input}\sqrt{I_p}$ characteristic of the tube should be as large as possible. On this basis the 6AK5 is a desirable input tube.

In obtaining Eq. (36), a term $\frac{4kT}{\omega^2 R}\left(\frac{R_s}{R}\right)$ has been neglected, since, in comparison with Eq. (30), this term is negligible ($R_s/R \approx 10^{-7}$ or smaller).

3. Computation of Signal-to-noise Ratio. The total mean square equivalent charge noise in unit frequency range is the sum of Eqs. (30), (33) and (36),

$$q_n^2 = 4kT\left[\left(\frac{1}{R}+\frac{1}{R_g}\right)\frac{1}{\omega^2}+R_sC^2\right] \qquad (37)$$

The noise in the output signal of the amplifier depends on the shape of the gain-frequency curve and on the absolute value of the gain. Since the absolute value of the gain affects signal and noise alike it is sufficient to consider only the normalized gain function $|g(f)|$ in computing noise. In the present discussion we shall limit our considerations to the case of an amplifier in which the low-frequency response is determined by a single time constant R_1C_1 due to a coupling of the form shown in Fig. 20*a*, and the high-frequency response is likewise determined by a single time constant R_2C_2 due to a plate load impedance of the form shown in Fig. 20*b*. All other time constants affecting the low-frequency response are supposed to be much longer than R_1C_1, and all other time constants affecting the high-frequency response are supposed to be much shorter than R_2C_2. For such an amplifier we have shown that

$$g(s) = \frac{sR_1C_1}{1+R_1C_1s} \times \frac{1}{1+R_2C_2s}$$

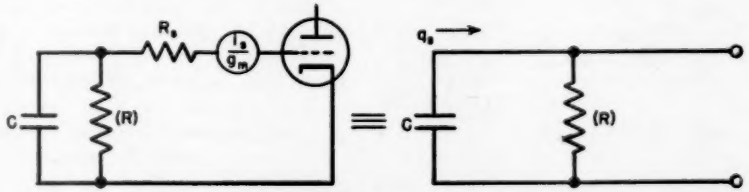

FIG. 19

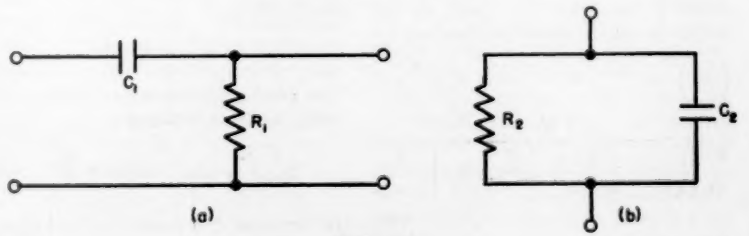

FIG. 20

Letting $s = j\omega(\sigma = 0)$ and introducing $f = \omega/2\pi$, we find that

$$|g(f)|^2 = \frac{f^2}{f^2 + f_1^2} \times \frac{f_2^2}{f^2 + f_2^2} \quad (38)$$

where $f_1 = \dfrac{1}{2\pi R_1 C_1}$ and $f_2 = \dfrac{1}{2\pi R_2 C_2}$

are the lower and upper half-power frequencies, respectively.

The mean square equivalent noise charge at the input, as affecting the output signal of the amplifier, may be written

$$Q_n^2 = \int_0^\infty q_n^2 |g(f)|^2 df,$$

which becomes, on substituting values from Eqs. (37) and (38), and carrying out the integration,

$$Q_n^2 = \frac{kT}{2\pi}\left\{\left(\frac{1}{R} + \frac{1}{R_g}\right)\left(\frac{f_2}{f_1(f_1 + f_2)}\right) + 4\pi^2 R_s C^2 \left(\frac{f_2^2}{f_1 + f_2}\right)\right\} \quad (39)$$

We have already derived an expression for the signal which appears at the amplifier output when a step signal is applied to the input. (This is equivalent to placing a charge suddenly on the input capacitance.) The output pulse is

$$e(t) = \frac{R_1 C_1}{R_1 C_1 - R_2 C_2}\left[\exp\left(-\frac{t}{R_1 C_1}\right) - \exp\left(-\frac{t}{R_2 C_2}\right)\right] \quad (40)$$

which has the amplitude

$$e(t)|_{max} = \lambda^{\frac{1}{1-\lambda}} \quad (41)$$

where $\lambda = R_1 C_1 / R_2 C_2 = f_2/f_1$. The signal-to-noise ratio (squared) at the amplifier output, therefore, becomes

$$\left(\frac{V_s}{V_n}\right)^2 = \frac{Q_s^2\, \lambda^{2/1-\lambda}}{\dfrac{kT}{2\pi}\left\{\left(\dfrac{1}{R} + \dfrac{1}{R_g}\right)\dfrac{1}{f_1} + 4\pi^2 R_s C^2 \lambda f_1\right\}\dfrac{\lambda}{1+\lambda}} \quad (42)$$

where Q_s is the charge placed on the input capacitance. The charge (signal) which, when placed on the input capacitance, gives a pulse equal in height to that produced by the most probable noise charge, Q_{mpn}, is found by making $(V_s/V_n) = 0.6745$ and solving for $Q_s = Q_{mpn}$.

Thus $Q_{mpn}^2 = (.67)^2 \dfrac{kT}{2\pi} \times$

$$\frac{\left\{\left(\dfrac{1}{R} + \dfrac{1}{R_g}\right)\dfrac{1}{f_1} + 4\pi^2 R_s C^2 \lambda f_1\right\}\dfrac{\lambda}{\lambda + 1}}{\lambda^{2/1-\lambda}} \quad (43)$$

Let us now examine some consequences of Eqs. (42) and (43). Two cases are of greatest interest: (1) that of achieving the highest possible S/N ratio without regard to pulse duration; (2) that of achieving the highest S/N ratio for a given pulse duration. A third case, that of achieving the highest S/N ratio for a given rise time of the amplifier, is of only limited interest. In all cases we shall assume that properties of the amplifier, not the collection time of the detector, determine the rise time of the signal.

Case 1. The signal-to-noise ratio given in Eq. (42) is a function of f_1 and $\lambda = f_2/f_1$. By usual methods, it is found that V_s/V_n is maximum when

$$f_1 = f_2 = \frac{1}{2\pi C\sqrt{R_g' R_s}}, \quad (44)$$

where $1/R_g' = 1/R_g + 1/R$. Since $\lambda = f_2/f_1 = 1$, we find that the relative signal height is

$$\lambda^{1/1-\lambda} = \frac{1}{e} = 0.3678 \cdots$$

The most probable noise charge [Eq. (43)], therefore becomes

$$Q_{mpn}^2 = (0.67)^2 e^2 kTC\sqrt{\frac{R_s}{R_g'}}. \quad (45)$$

In terms of the number of electrons, ($T = 300°$ A)

$$Q_{mpn} = 735\ C_{\mu\mu f}{}^{1/2} \sqrt{\frac{R_s}{R_g'}} \text{ electrons.} \qquad (45a)$$

According to Terman (3, p. 294), for a typical triode $R_s = 3/g_m$ ohms and for a pentode

$$R_s = \frac{I_{plate}}{I_{plate} + I_{screen}} \left(\frac{2.5}{g_m} + \frac{20 I_{screen}}{g_{m\ screen}} \right) \text{ ohms}$$

For a 6AK5 with R_g infinite (floating grid)

$$R_s = \frac{.005}{.005 + .002} \left(\frac{2.5}{.004} + \frac{20 \times .002}{.001} \right) \text{ ohms}$$

$$\doteq 650 \text{ ohms},$$

and $R_g' \doteq 10^9$ ohms.

It is likely that these values are correct only as to order of magnitude.

If C = 20 $\mu\mu$f, then $Q_{mpn} = 735 \times 5 \times .028 \approx 100$ electrons, in agreement with the calculation of others (5). The half-power points of the amplifier are at

$$f_1 = f_2 = \frac{1}{2\pi 20 \times 10^{-12} \sqrt{6.5 \times 10^{11}}} = 10{,}000 \text{ cps}$$

The rise time of such an amplifier is about $\sqrt{2\pi}\ R_2C_2 = 2.5 \times 16 = 40$ μsec and $R_1C_1 = 16$ μsec (the "clipping time"). Two pulses would not overlap if separated about 60 μsec. Hence one could count about 160 random pulses per second with only one percent of the pulses appreciably overlapping each other.

Case 2. Evidently for many applications it is desirable to employ pulses of duration shorter than that required for optimum signal-to-noise ratio. To treat this case it is necessary to define pulse duration. This may be done in a manner analogous to that employed for rise time. If $g(s)$ is the normalized gain function of the amplifier then a pulse

$$e(t) = \mathfrak{L}^{-1}\left[\frac{1}{s}\, g(s)\right]$$

has the typical form indicated in Fig. 21.

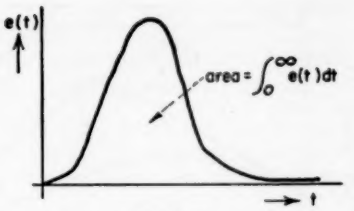

FIG. 21

It is found convenient to define pulse duration τ by the relation

$$\tau^2 = \frac{2\pi \int_0^\infty (t - t_0)^2 e(t)\,dt}{\int_0^\infty e(t)\,dt} \qquad (46)$$

where $t_0 = \dfrac{\int_0^\infty te(t)\,dt}{\int_0^\infty e(t)\,dt}$ is the centroid of the pulse.

Equation (46) states that the duration of a pulse is $\sqrt{2\pi}$ (= 2.5) times the standard deviation of the pulse $e(t)$. This definition has the advantage that it leads to a ready means for evaluating the duration from the system function $g(s)$. (Details of this calculation will not be given here, but they can be readily supplied if one follows the method used for computing rise time given earlier.) For the "RC-RC" amplifier it turns out that

$$\tau = T_R(1 + \lambda^2)^{1/2} \qquad (47)$$

where $T_R (\equiv \sqrt{2\pi}\ R_2C_2)$ is the rise time and $\lambda \equiv R_1C_1/R_2C_2$. We now must maximize the signal-to-noise ratio, Eq. (42), subject to Eq. (47). Since the frequencies involved are considerably higher than those occurring in Case 1, the term involving grid resistances in the denominator in Eq. (42) can be neglected. The maximum S/N ratio again occurs at $\lambda = 1$ ($R_1C_1 = R_2C_2$). A plot of the relative signal-to-noise ratio for this case, as a function of $T_R/R_1C_1 = T_R/T_1 = \lambda/\sqrt{2\pi}$ is shown

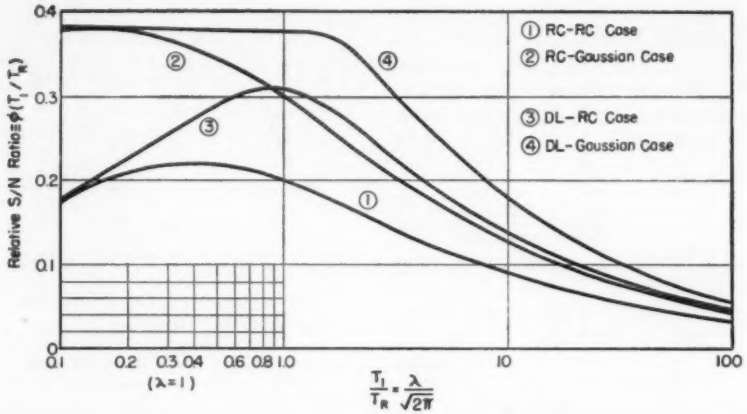

FIG. 22. Relative signal-to-noise ratios as a function of the ratio of clipping time to rise time: for constant pulse duration

in Fig. 22 as curve 1. This curve is useful for estimating the effect on rise time of different ratios of rise time to the time constant T_1 (the "clipping time"), for constant pulse duration.

It is of interest to estimate the most probable number of (equivalent) noise electrons occurring as a function of C, R_s, τ and the parameter $T_1/T_R = \lambda/\sqrt{2\pi}$. To simplify matters all numerical factors in Eq. (43) have been combined together into an equation to be used with the relative signal-to-noise graph $\phi(T_1/T_R)$. The resulting expression

$$Q_{mpn} = 0.22 C_{(\mu\mu f)} \sqrt{\frac{R_{s(ohms)}}{\tau_{(\mu sec)}}} \frac{1}{\phi(T_1/T_R} \text{ electrons} \quad (48)$$

is in reasonable agreement with some measurements made on the noise of an amplifier having a rise time of about 0.15 μsec, and a "clipping time" of 5 μsec.

It is evident from the curve $\phi(T_1/T_R)$ that an optimum S/N ratio is achieved if the rise time and "clipping time" are about equal. It is clearly poor practice to use an amplifier where T_1 is considerably longer than T_R, although this practice is one commonly adopted.

The other curves Fig. 22 show the relative signal-to-noise ratio for a Gauss-error-curve shape of cut-off with RC clipping (curve 2) and the analogous curves for delay-line clipping. A somewhat higher S/N ratio is obtained with a delay-line clipper and a Gaussian cut-off at high frequencies. These curves can be used in conjunction with Eq. (48). (The use of a delay line for clipping pulses will be discussed briefly in Sec. XI.)

Where it is necessary to preserve a fast rise of the pulse—for instance, in certain coincidence or timing experiments—the signal-to-noise ratio turns out to be highest when $T_1 \gg T_R$ provided the amplitude of the pulse is still taken as a measure of the signal. Details of this computation follow along lines similar to those used for the other cases. One keeps T_R fixed and maxi-

mizes the S/N ratio varying T_1 (or f_1). The values of the S/N ratio so computed are considerably smaller than those which could be obtained for a pulse of the same duration, but of different shape (*i.e.*, lacking a steep front).

In the usual coincidence experiment, however, the amplitude of the pulse is of no great consequence, so it appears likely that the results of Case 2 apply to most cases of coincidence counting. This conclusion has been called to the attention of the author by M. L. Sands.

V. Some Remarks on the Design of Pulse Amplifiers (*6*).

A general type of arrangement often used in counting particles is shown in Fig. 23. The following matters should be considered in designing the amplifier:

1. Sign of input pulse—usually negative.

2. Sign of output pulse—always positive—(cathode-follower output).

3. Magnitude of output pulse—10 to 100 v desirable, on account of discriminator stability ($\pm$ a few tenths of a volt).

4. Gain (voltage) of amplifier—2×10^5 to 10^6 (to bring noise up to a few volts).

5. Gain control, smooth and coarse, covering continuously or in small steps, a range of perhaps 30 in voltage amplification. (If a greater range must be covered, substitute a cathode follower pre-amplifier with gain < 1)

6. Linearity—say one percent departure for largest pulse (?)

7. Stability—variations in gain less than one percent, caused by line variations and components changing.

8. Rise time?—coincidence measurements?

9. Pulse duration?—pile-up?—signal-to-noise ratio? And counting rate? Fairly short to avoid trouble with microphonics.

10. Position of gain control—*chosen to prevent preceding stage from overloading.*

11. Position of pulse shaping network—chosen to avoid preceding stage overloading due to pile up of pulses; and to reduce noise from early stages—RC or delay line?

12. Ordinary or feedback amplifier?

a) *Ordinary:* Very short rise time more readily achieved. Poor linearity and gain stability.

b) *Feedback:* Greater linearity, stability but difficult to build with a rise time much shorter than 0.1 μsec (gain 3×10^5). Rise time not very well stabilized when shortest rise time is obtained. Should control rise time in β-path or between feedback loops—not in μ-path.

13. Shielding and installation to prevent pick-up of external transients.

14. Monotonic transient response to a step signal.

The above list, written down some-

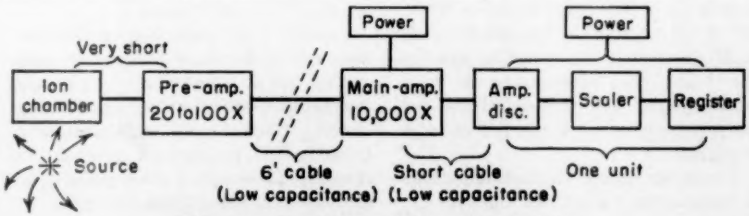

FIG. 23. Arrangement for counting particles

what at random, is not complete, but is suggestive of most of the factors which should be considered in designing a pulse amplifier.

Before a discussion of basic types of circuits, it is well to consider briefly the nature of the signal undergoing amplification. If n is the average counting rate, then the probability that a second pulse will occur in the time interval t to $t + dt$ following a given pulse (at $t = 0$) is simply

$$p(t)dt = ne^{-nt}dt$$

We note that $p(t)dt$ is largest for small values of t; in fact, it is simply ndt. Thus, if $n = 10^3$ counts per second, then one percent of the counts will be separated 10 μsec or less.

Now the voltage at the input grid consists of the random superposition of exponential signals of the form

$$e(t) = \frac{Q_0}{C} \exp\left(-\frac{t}{RC}\right) = e_m \exp\left(-\frac{t}{RC}\right) \quad (49)$$

where R is the grid leak, C is the total effective capacitance at the input and Q_0 is the charge collected from the ionization process in the gas of the ion chamber (for each entering particle).

The average voltage produced by the random superposition of voltages of the form given by Eq. (49) is

$$\overline{e(t)} = n \int_0^\infty e(t)dt = nRCe_m \quad (50)$$

where n is the average rate of occurrence. In an extreme case, $n = 10{,}000$ per sec, $R = 10^8$ ohms, $C = 10^{-10}$ farads, $e_m = 10^{-2}$ volts, so $e(t) = 10^4 \times 10^8 \times 10^{-10} \times 10^{-2} = 1.0$ volt, which is sufficient to shift the operating point of the input grid appreciably if it is direct-coupled to the electrode of the ion chamber. Usually this effect is negligible.

The mean square fluctuation voltage is found from Campbell's theorem (7) as follows:

$$\overline{(e(t) - \overline{e(t)})^2} = n \int_0^\infty [e(t)]^2 dt$$

or

$$v_f^2 = n \frac{RC}{2} e_m^2 \quad (51)$$

(when $e(t)$ is given by Eq. (49)).

For the case considered before,

$$v_f^2 = \frac{10^4 \times 10^8 \times 10^{-10} \times e_m^2}{2}$$

or

$$v_f \approx 7e_m \quad (51a)$$

This fluctuation voltage causes no trouble at the input grid, but if the signal there is amplified faithfully, the amplifier will overload at some point farther along because of the fluctuation voltage (long before individual pulses cause it to overload). The actual peaks in the fluctuation voltage (often referred to as "pile-up") will be perhaps 3 times the rms value, so it is well *to allow an overload factor of* 20 *times the amplitude of individual pulses.* The phenomenon just described influences the choice of position where the short-time-constant, pulse-shaping network is placed. Since such a time constant is much shorter than the RC of the input circuit, the fluctuation voltage following it is practically nil. Usually the pulse-shaping circuit is placed between the preamplifier (gain 30 to 100) and the main amplifier (gain 10,000). It is desirable to place it as far along in the amplifier as is compatible with the fluctuation phenomenon just described. The reason for this, of course, is that it acts as a filter for hum, microphonics, and other low-frequency noise components arising in the early stages.

Usually it is found convenient and satisfactory to place the coarse gain control (an attenuator) at the place in the amplifier used for the pulse-shaping circuit. Careful consideration must be given to the problem of overload in choosing the range of attenuation (due consideration being given, of course, to the fluctuation voltage).

The design of amplifiers having no feedback requires little comment, and will not be discussed. The main difficulties are concerned with the high-level stages where great care in choosing operating points is needed to avoid non-linearity of reponse. Often to secure sufficient linearity it is necessary to use a certain amount of feedback, such as that afforded by an unbypassed cathode resistor. The following characteristics are typical of a fast, critically shunt-compensated amplifier containing about 9 stages (including 2 cathode followers):

Gain: 200,000
Reasonably linear output (positive pulses): 40 v.
Rise time: 0.06 μsec.
Stability: 4 % change in amplification for 1 % line variation (due to changes in cathode temperature).
Power supply: 250 v, 200 ma, stabilized.

Let us consider a type of three-tube feedback loop which has proved useful in pulse amplifier design. The basic circuit is shown in Fig. 24, where representative values are given for some of the components. The voltage gain (with feedback) is usually made to lie in the range 20 to 100.

Some notes on the design of a feedback loop of this sort may be listed as follows:

1. The gain is determined (to within about 5 percent) by the ratio $\frac{R_1 + R_2}{R_2}$.

2. The small capacitance C_1 is used to "feed-back-the-highs" to provide a good (monotonic) transient response.

3. The time constant R_0C_0 should differ considerably from R_3C_3 (if the latter is used).

4. The resistor R_2 provides cathode bias for T-1 as well as helping to determine the gain.

5. Tubes are usually operated about as recommended in tube handbooks, *i.e.*, as regards screen, plate voltages, currents, etc.

6. The stray wiring capacitance of all signal-carrying leads is kept at a minimum.

7. For very good gain stability the resistors R_1 and R_2 should be wire-wound, but essentially non-inductive.

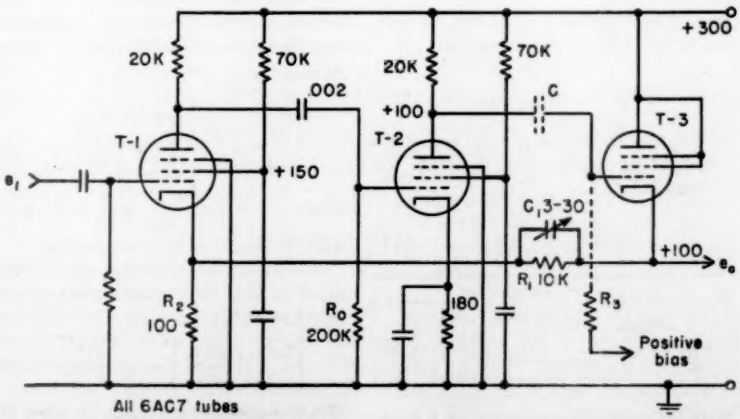

FIG. 24. Typical (basic) feedback loop. The voltages given are only approximate

8. Stages T-2 and T-3 should be asymmetrically biased if they must handle large signals of one sign.

9. The load placed on T-3 must be essentially *resistive*. Even a small capacitive load causes an adverse phase shift in the feedback voltage, leading to poor transient behavior or even continuous oscillations. (One cannot even hang a 'scope lead on the output!)

10. If the plate load resistor of T-3 is made inductive (shunt compensation), the transient behavior for fast, especially large, signals is improved.

11. The signal can be inverted by placing a suitable resistance in series with the plate of T-3 and taking the output signal from the plate. If this is done, the value of R_1 is not critical and it can be reduced in value.

12. In building the amplifier, considerable care should be taken in the arrangement of ground leads and in laying out the circuit so as to avoid undesirable interactions.

13. When more than one feedback loop is employed, it is necessary to decouple the addi.ional loops by use of resistance-capacitance filters in their plate leads. (Inadequate decoupling causes motorboating at a low frequency.) The decoupled loops, of course, are designed to operate at a lower plate voltage.

VI. An Approximate Transient Analysis for a Two-stage Feedback Amplifier

We shall consider the transient response of the idealized amplifier shown in Fig. 25, corresponding roughly to the feedback loop just described. The fraction of the output signal fed back is

$$\beta(s) = -\frac{R_2}{R_2 + \dfrac{R_1}{1+\tau_1 s}} = \beta_0 \frac{1+\tau_1 s}{1+\tau_1 \beta_0 s} \qquad (52)$$

where $\beta_0 = \dfrac{R_2}{R_1 + R_2}$, $\tau_1 = R_1 C_1$. The gain of the feedback amplifier, according to the well-known theory, is

$$A(s) = \frac{G(s)}{1+\beta(s)G(s)}. \qquad (53)$$

We are interested in a two-stage amplifier having the gain function (or system function)

$$G(s) = \frac{G_0}{(1+\tau s)^2}, \qquad (54)$$

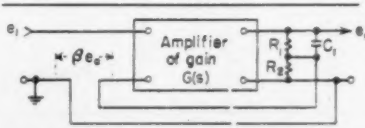

FIG. 25. Equivalent circuit of a feedback amplifier

which is recognized as the gain of the equivalent high-frequency amplifier having two R-coupled stages each with a plate time constant $RC = \tau$. The gain G_0 may be computed from

$$G_0 = g_m^2 R^2 \qquad (55)$$

where g_m is assumed to be the same for each amplifier tube. (In a typical pulse amplifier, $G_0 \approx 10^4$ and $\beta_0 \approx 10^{-2}$.) When β_0 is small, Eq. (52) can be simplified by neglecting the term $\beta_0 \tau_1 s$ as compared with unity. We then find that Eqs. (52), (53) and (54) give

$$A(s) = A_0 \frac{1}{1 + \left[\dfrac{2\tau + \beta_0 G_0 \tau_1}{1+\beta_0 G_0}\right] s + \dfrac{\tau^2 s^2}{1+\beta_0 G_0}} \qquad (56)$$

where $A_0 = \dfrac{G_0}{1+\beta_0 G_0} \approx \dfrac{1}{\beta_0}$ is the gain, with feedback, at low frequencies.

For critical compensation the denominator of Eq. (56) must have two real equal roots, *i.e.*,

$$\left[\frac{2\tau + \beta_0 G_0 \tau_1}{1+\beta_0 G_0}\right]^2 = \frac{4\tau^2}{1+\beta_0 G_0}. \qquad (57)$$

Hence τ_1 must be chosen to have the value

$$\tau_1 = \frac{2\tau}{\beta_0 G_0}\left(\sqrt{1+\beta_0 G_0} - 1\right)$$
$$= \frac{2\tau}{\sqrt{\beta_0 G_0}}\left(1 - \frac{1}{\sqrt{\beta_0 G_0}} + \cdots\right),$$

or

$$\tau_1 \approx \frac{2\tau}{\sqrt{\beta_0 G_0}} \qquad (58)$$

Since in a typical amplifier $\beta_0 G_0 \approx 100$, the time constant τ_1 should be about $\frac{1}{5}\tau$. If $\tau = RC = 10^4 \times 25 \times 10^{-12} = .25$ μsec, then $\tau_1 \approx .05$ μsec, *i.e.*, $C_1 = 5$ μμf is required for $R_1 = 10^4$. This computation of C_1 checks fairly closely the magnitude of the compensating capacitance C_1 found to be required empirically for the amplifier of Fig. 24, to insure a monotonic transient response to a step function.

The rise time of this amplifier is found by the method described in Sec. III to be

$$T_R = \sqrt{2\pi} \times \sqrt{2}\,\frac{\tau}{\sqrt{1+\beta_0 G_0}}, \qquad (59)$$

when τ_1 is chosen for critical compensation. For the typical amplifier having the constants given above, Eq. (59) gives the value $T_R = .087$ μsec, in reasonable agreement with measured performance. The value of the rise time is evidently very sensitive to changes in G_0. The gain-rise time quotient is

$$\frac{A_0}{T_R} = \frac{G_0}{1+\beta_0 G_0}\,\frac{\sqrt{1+\beta_0 G_0}}{\sqrt{2\pi}\,\sqrt{2}\,\tau}$$
$$= \sqrt{\frac{A_0}{2}}\left(\frac{g_m}{\sqrt{2\pi}\,C}\right). \qquad (60)$$

For the sake of comparison, let us compute the same quantity for a two-stage R-coupled amplifier having the same gain but no feedback, *i.e.*, the plate load resistors R_0 are chosen to make $g_m^2 R_0^2 = A_0$. Such an amplifier has the rise time $T_R = \sqrt{2}\cdot\sqrt{2\pi}\,R_0 C$. Therefore,

$$\frac{A_0}{T_R} = \frac{g_m^2 R_0^2}{\sqrt{2}\cdot\sqrt{2\pi}\,R_0 C}$$
$$= \sqrt{\frac{A_0}{2}}\left(\frac{g_m}{\sqrt{2\pi}\,C}\right), \qquad (61)$$

which is identical with Eq. (60). Feedback of the sort employed evidently does not (1) increase the gain-rise time quotient; (2) stabilize the rise time. It does improve linearity and stabilize the gain for signals lasting for times long compared with the rise time.

It is of interest to examine the case where τ_1 is increased in order to increase the rise time. Let us assume, therefore, that

$$\tau_1 \gg \frac{2\tau}{\sqrt{\beta_0 G_0}}, \qquad (62)$$

the approximate value for critical compensation. Equation (56) then becomes

$$A(s) \doteq A_0\,\frac{1}{1+\beta_0 A_0 \tau_1 s}. \qquad (63)$$

The normalized transient response to a step function is now

$$e(t) = 1 - \exp\left(-\frac{t}{\beta_0 A_0 \tau_1}\right)$$
$$\approx 1 - \exp\left(-\frac{t}{\tau_1}\right) \qquad (64)$$

and the rise time is

$$T_R = \sqrt{2\pi}\,\beta_0 A_0 \tau_1 \approx \sqrt{2\pi}\,\tau_1 \qquad (65)$$

which depends very little on the unfedback gain $G_0 = g_m^2 R^2$. The transient response (64) is the same as that of a single-stage, R-coupled amplifier.

An analysis of the sort used for the high-frequency equivalent amplifier can be employed for the low-frequency equivalent amplifier. If such an amplifier contains a single plate-to-grid time constant T_1, it is found that feedback effectively lengthens it by a factor $(1 + \beta_0 G_0)$. When there are two time constants involved, then a slow damped oscillation is produced in response to a

step function unless one of the time constants

$$T_2 > 4\beta_0 G_0 T_1 \text{ (approximately).} \quad (66)$$

In practice no difficulty is found if one time constant is made perhaps 50 times the other. For example, $T_1 = R_1C_1 = 10^5 \times 10^{-9} = 10^{-4}$ and $T_2 = R_2C_2 = 5 \times 10^5 \times 10^{-8} = 5 \times 10^{-3}$ are found satisfactory. If $\beta_0 G_0 \approx 100$, then the effective time constant $\approx 100 \times 10^{-4} = 10^{-2}$, corresponding to a lower half-power frequency of about 15 cps.

VII. Discriminators and Scaling Circuits (*8*)

Pulses from a pulse amplifier can be counted for subsequent analysis in several ways, the most common one involving the use of a scaling circuit followed by a message register. Other well-known methods involve the use of a counting-rate meter or the use of an oscilloscope and a moving-film camera. In special applications it may be desired to count pulses having a particular time relationship with other pulses occurring either at random, or at a repetition rate related to the modulation of the primary source of nuclear particles (*e.g.*, the neutron spectrometer which makes use of the time-of-flight of neutrons).

1. Discriminators. In most counting applications it is necessary to select pulses for counting using the criterion of pulse amplitude: pulses smaller than some particular size being ignored. The device used to accept or to reject pulses according to their amplitude can be termed a pulse amplitude discriminator, or simply a discriminator. Such a device is required in the majority of counting circuits, primarily for two reasons:

1. To prevent background pulses, usually from noise sources, from counting.

2. To select pulses according to the energy of the particles entering the electrical detector.

A suitable discriminator circuit should possess the following properties:

1. It should discriminate between pulses differing in amplitude by a small fraction of 1 volt, and be stable to a similar extent.

2. It should be suitable to use with pulses of the shape and duration provided by pulse amplifiers, *i.e.*, it should respond only to the amplitude and not the shape or duration of the pulses, within certain broad specified limits.

3. It should not overload readily, *i.e.*, its bias should not shift, for large pulses or for pulses occurring in rapid succession (within specified limitations, of course).

4. It should deliver a standard signal which is suitable for triggering a scaler, or other device such as a counting-rate meter. The shape and duration of the trigger should be consistent with the resolving time of the scaler or other device.

5. The discrimination voltage or bias should be readily adjusted.

The simplest type of discriminator can be based on a sharp cutoff tube, for instance a pentode, which is biased off a specified amount. A more complicated discriminator involves a biased diode, used in conjunction with an amplifier, and a trigger circuit. Considerable care in design is necessary if discriminators of these types are to meet the requirements listed above, although very satisfactory circuits can be based on the biased diode. It would appear that the most useful discriminator for the majority of applications is one based on the Schmitt trigger circuit (*9*), or some modification of it. A typical diagram for such a discriminator is indicated in Fig. 26.

The circuit shown is satisfactory for counters having a resolving time as short as a few microseconds. With modifications the basic circuit can be used for very fast counting (resolving

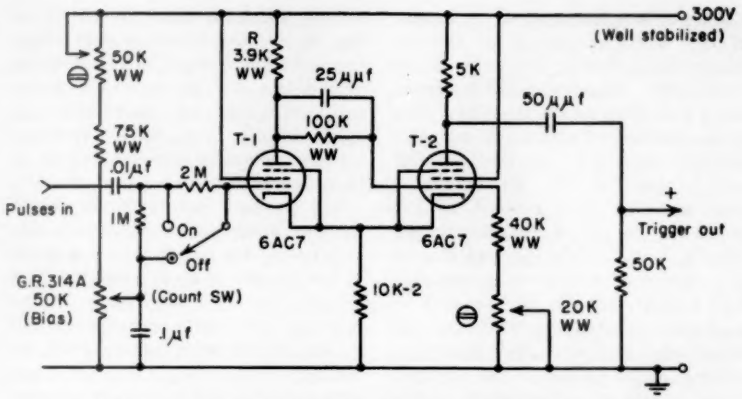

FIG. 26. Pulse-height discriminator based on Schmitt trigger circuit

time perhaps 0.3 μsec).

The basic requirements of a discriminator are met by the circuit given. Its operation, which is characteristic of the Schmitt type of circuit, is based on the fact that either T-2 or T-1 is conducting, depending on the potential of the grid of T-1. The resistor R in the plate circuit of T-1 controls the *hysteresis* of the trigger circuit. (By hysteresis is meant the phenomenon that the potential at which the grid of T-1 causes triggering for an increasing pulse is higher than that for the decreasing or trailing edge of the pulse.) Some hysteresis—a few volts—is necessary to avoid oscillations (multivibrating) if the potential of the grid of T-1 is held at the triggering potential.

Each pulse whose amplitude causes the grid of T-1 to remain above the triggering potential for 0.1 μsec or longer, produces a positive trigger pulse to occur at the plate of T-2, sufficient in amplitude to trigger a flip-flop scale-of-two (a coupling stage may be necessary, depending on how the scale-of-two is triggered). It is found that the amplitude of the input pulse can rise about 100 volts above the triggering potential before grid current is drawn by T-1, thereby shifting the d-c bias voltage.

For stability of discrimination the power supply must be well stabilized and the resistors marked WW should be wire-wound. It is not necessary to provide stabilized heater voltage for the two 6AC7 heaters, since changes in grid-cathode (effective) contact difference-in-potential are minimized by the balanced nature of the circuit. With precautions, the discrimination voltage will remain constant to ±0.2 volt measured over a period of several days, although it may change more than this if the tubes are changed.

It is worth noticing that the signal at the plate of T-2 is suitable for intensifying the trace of an oscilloscope used for recording pulse amplitudes on a moving-film camera. Intensification is often necessary to avoid an undue exposure of the undeflected trace. It is usually necessary to employ a cathode-follower coupling stage to preserve the fast rise of the intensifier pulse.

2. A Scale-of-two Circuit Element. A scaling circuit of great usefulness is one based on a sequence of scales-of-two.

A scale-of-two circuit element consists of two tubes connected to form a trigger circuit having two stable states (a flip-flop). The principal difficulty in using a flip-flop as a scale-of-two rests in the problem of securing a unilateral coupling between adjacent flip-flop circuits and between the discriminator and the first flip-flop in the sequence. In many of the older scaling circuits, the coupling required the use of an isolating amplifier stage together with a short-time-constant network to minimize undesirable interactions and to provide a pulse of suitable (and often critical) shape to trigger the flip-flop. Even at best a scaling circuit of this sort usually required frequent "alignment" for satisfactory operation.

A scale-of-two circuit element, which has proved to be very satisfactory for moderately fast counting rates (resolving time 3–5 μsec), is shown in Fig. 27. If the values in parenthesis are used, (including a 6SL7 tube) the scale-of-two will consume less power and have a resolving time of about 20 μsec. Usually two 6SN7 elements are used preceding four 6SL7 elements to make a scale-of-64.

The unusual feature of the circuit element is the use of diodes to couple unilaterally the signal from one scale-of-two to the next, *i.e.*, the terminal "OUT" is connected directly to the terminal "IN" of the next element, and so on for as many scales-of-two as desired. When T-2 of the preceding stage becomes conducting, a negative step signal is applied to the plate of the "OFF" tube, and through the RC network to the grid of the adjacent "ON" tube. This causes the flip-flop to pass to its other stable state.

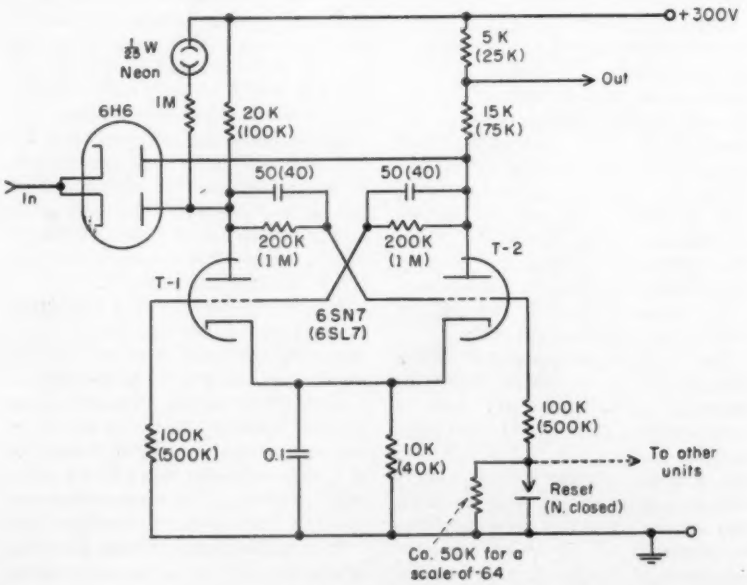

FIG. 27. Scale-of-two

When T-2 of the preceding stage becomes non-conducting, the resulting positive step signal does not change the state of the trigger pair. A consideration of the circuit shows that this method of triggering (or any other method, for that matter) will not be successful unless the capacitors in the cross coupling between grids and plates are large enough to over-drive the grids. Furthermore, the biasing should insure that the conducting tube draws some grid current. In practice it is found that a scale-of-two of this type will always work satisfactorily if pairs of components are within ten percent of one another. No special alignment procedure is necessary

The discriminator of Fig. 26 can be coupled to the first scale-of-two as shown in Fig. 28. The use of such a coupling stage (1) provides a negative trigger, (2) supplies the trigger at the correct d-c level to the diodes in the first scale-of-two. To couple very narrow pulses to the scale-of-two, it may be well to replace the triode stage by a sharp cut-off pentode.

A typical output section for driving a message register is shown in Fig. 29. The basic problem in designing a circuit of this sort is to provide an essentially rectangular voltage pulse, as large

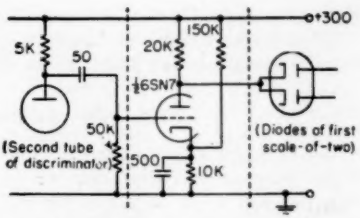

FIG. 28. Coupling stage between discriminator and scale-of-two

as convenient, for the length of time required to operate the register. The circuit should then recover more rapidly than the register so that properties of the register itself provide the factors limiting its speed of operation. An examination of Fig. 29 indicates that the ½6SL7 is normally conducting, whereas the 6V6 is normally cut off. When a negative step signal comes from the last scale-of-two, the ½6SL7 is cut off and grid current is drawn by the 6V6. This continues for about 0.01 sec, *i.e.*, until the ½6SL7 is again conducting, and, therefore, the 6V6 is again cut off. The ½6SL7 can be conveniently made the half of a 6SL7 left over in the stabilized power supply. The time constants in the grid circuits of Fig. 29 may have to be lengthened

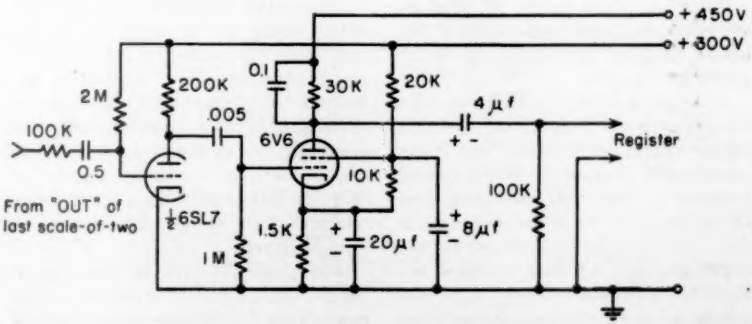

FIG. 29. Circuit for driving a message register

if the register used is slow in operation.

Other output circuits are based on a thyratron (such as the 2050), or on a cathode follower arranged to supply a pulse of several hundred volts amplitude.

VIII. Differential Amplitude Discriminators

The distribution in amplitude of pulses from an electrical detector of radiation can be measured in several ways:

1. If the source is steady, an *integral* bias curve can be secured with a simple discriminator coupled to a scaling circuit.

2. If the source is unsteady, the same information can be obtained using two such circuits. The bias of one discriminator is then kept fixed, and the counts from it used to normalize the counts from the discriminator of variable bias. In both these methods the *differential* bias curve can be found by analysis.

3. Since the differential bias curve is normally of more interest than the integral curve, it is convenient to obtain it directly using a differential discriminator, *i.e.*, one which responds only to pulses whose amplitudes lie between definite limits. A third discriminator held at a fixed bias can furnish a normalizing count. Such a single-channel differential discriminator reduces the counting rates to be measured and the time required to obtain a differential bias curve. It also insures a more stable separation of the biases defining the range in which pulses are counted.

4. A multi-channel differential discriminator is an obvious extension of a single-channel discriminator, and it can considerably shorten the time required to obtain a differential bias curve, since all pulses which occur are sorted as to size. Not only is the decrease in time important, but the data obtained are likely to be more consistent, since conditions need remain constant only for a short time.

The saving in time by using a single-channel differential discriminator, as compared with using a simple discriminator set successively at two different biases, may be estimated as follows. Let N_1 be the number of pulses of amplitude greater than A_1 and N_2 those with amplitude greater than A_2, $(A_2 > A_1)$, both sets of counts taken in time T. The rms error in N_1 is $\sqrt{N_1}$ and that in N_2 is $\sqrt{N_2}$. The *fractional* rms error in the differential count $N_1 - N_2$ is $\sqrt{N_1 + N_2}/(N_1 - N_2)$. To obtain this accuracy a time $2T$ is required. If one counts for a time t with a single-channel differential discriminator, then $\frac{t}{T}(N_1 - N_2)$ counts are obtained with a fractional rms error of $1 \Big/ \sqrt{\frac{t}{T}(N_1 - N_2)}$. Equating the two fractional rms errors we find that $t/T = (N_1 - N_2)/(N_1 + N_2)$, where it should be recalled that T is the time for N_1 (or N_2) counts. Hence, to secure a certain statistical accuracy, the time required with the differential discriminator is reduced by the factor $(N_1 - N_2)/2(N_1 + N_2)$.

Differential discriminators are ordinarily based on an array of simple amplitude discriminators whose biases are progressively and accurately increased. By means of coincidence circuits connected between adjacent discriminators in the array, a count is recorded only in the channel separating the discriminators which have been triggered from those which have not been triggered.

The chief difficulty in designing a differential discriminator for fast pulses arises from the varying times at which succeeding discriminators are triggered,

first when the pulse is increasing in amplitude and later when it returns to its base line. Evidently a number of coincidence circuits pass through a sensitive state as the pulse increases and then decreases, and it is only the coincidence circuit between the highest discriminator triggered and the following one that should furnish a pulse to its counting circuit.

Difficulties of this sort have led to a design where those discriminators which are triggered remain temporarily in their second state, thus giving time for the input pulse to decay to zero. A delayed pulse initiated by the discriminator of lowest bias then serves to register the state of the coincidence circuits by sending on a pulse from the one in the anti-coincidence state. A second pulse delayed still longer finally resets all the discriminators, and the circuit is ready for another incoming pulse. A block diagram indicating this mode of operation for two channels is shown in Fig. 30. The extension to many channels can be readily made.

Let us now examine the discriminator and coincidence circuit, shown in Fig. 31, which is the basis of a successful multi-channel differential discriminator (*10*).

Tubes T-1, T-2 and T-3 constitute a variant of the Schmitt trigger circuit, with T-3 acting as a constant-current device, replacing the usual cathode resistor. The presence of T-3 enables the discriminator to receive pulses as large as 150 volts without grid current being drawn by T-1. (Grid current changes the bias voltage and so must be avoided.) Tube T-4 (½6SN7) is cou-

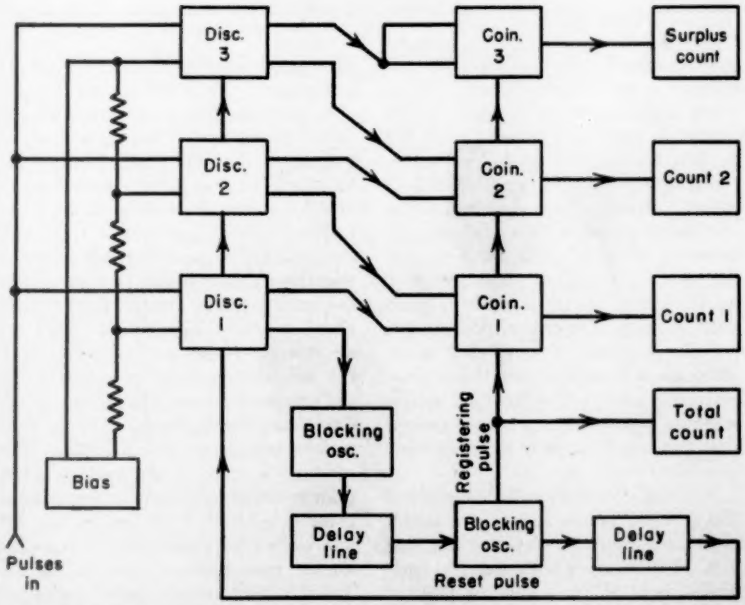

FIG. 30. Block diagram for a multi-channel discriminator (two channels shown)

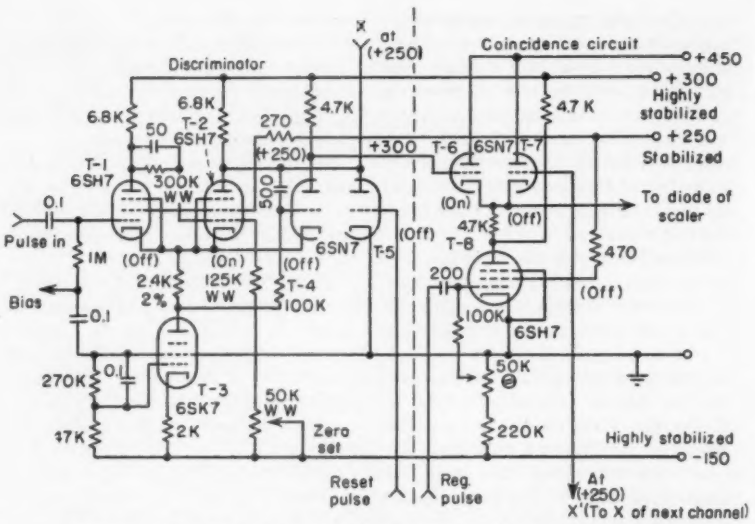

FIG. 31. Simplified diagram of discriminator and coincidence circuits

pled to tube T-2 so that the pair constitutes a sort of univibrator. Thus, when a plus pulse at the grid of T-1 causes the current to transfer from T-2 to T-1, the positive signal coupled to the grid of T-4 (from the plate of T-2) causes T-4 to conduct, thereby holding the three cathodes at a high enough potential that T-1 and T-2 are both cut off when the input pulse decays to its base line. Later a positive reset pulse supplied the grid of T-5 returns the discriminator to its original state, although it would return there automatically after a few hundred microseconds. (This latter provision insures that the circuit is ready to work when it is first turned on.)

The signals supplied to the grids of T-6 and T-7 of the coincidence circuit are taken from the plates of T-2 and T-3. Before being triggered, the plate of T-2 is at +250 v and the plate of T-3 at +300 v. If both discriminators are triggered, these potentials become interchanged. Evidently an input pulse of suitable amplitude causes one coincidence circuit in the sequence to have two signals of +250 v, all other circuits have one or the other connection at +300. Hence, when a registering pulse arrives at the grid of tube T-8, the one circuit differing from the rest allows a negative signal of about 50 v to pass to the scaler. (The other circuits pass along negative signals too small to affect their scalers.) The pulse from the coincidence circuit is generated at the correct d-c level (300 v) to permit direct coupling to the diode of the first scale-of-two circuit (See Fig. 27). The conducting state of the various tubes prior to the occurrence of an input pulse is indicated by (off) or (on) in Fig. 31.

A circuit for generating the registering and reset pulses is shown in Fig. 32. Tube T-2 receives a pulse (positive) each time the discriminator of lowest

bias is triggered. At a time which can be chosen to be 2.5, 5, or 10 μsec later, a registering pulse is generated by the blocking oscillator based on tube T-7. The same pulse emerges still later by 0.5 μsec through the cathode follower T-8 to serve as the reset pulse. The roles played by the various tubes may be listed as follows:

T-1—Diode restorer, to dump charge from the 50-μμf capacitor in the differentiating network (to speed recovery).

T-2—Cathode follower, to drive the grid of T-3.

T-3—Trigger-coupling stage, normally biased off. This stage and the cathode follower prevent the violent blocking oscillator pulse from feeding back to the discriminator.

T-4—Blocking oscillator, driving a lumped-parameter delay line which determines the registering pulse delay.

T-5—Low-impedance negative bias source for the two blocking oscillators. (A standard method of securing "Class C" bias.)

T-6—Trigger-coupling stage, normally biased off.

T-7—Blocking oscillator which generates the registering pulse. This pulse passes through a "count" switch (not shown) to turn on the differential discriminator.

T-8—Cathode-follower stage to deliver the reset pulse.

The total count is recorded by counting (with a scaler) the number of registering pulses.

The bias voltages supplied to the various discriminators can be obtained with a bleeder arrangement made from precision wire-wound resistors, connected between the −150-v bus and ground. It is convenient to be able to vary the channel widths in a few fixed steps, (*e.g.*, 10 v, 5 v, 2 v) and to move the entire sequence up or down in fixed steps. It is also desirable to provide a means of making all biases identical. When this is done, the "zero set" adjustments for each discriminator can be varied until all discriminators are triggered by the same pulse.

To test and to calibrate the channel

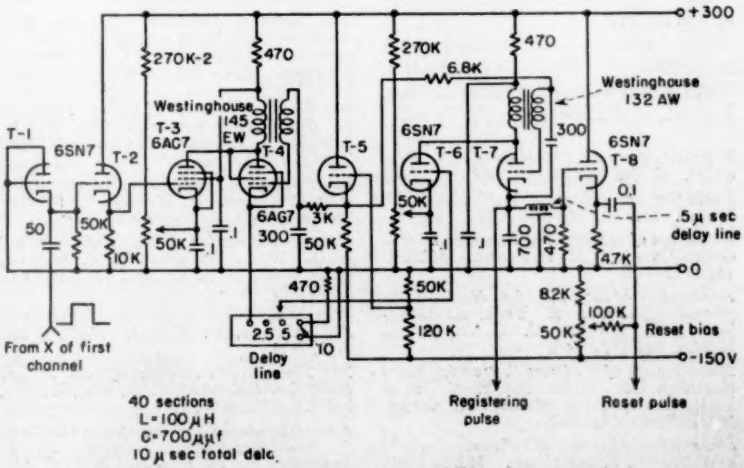

FIG. 32. Pulse generating circuits for differential discriminator

widths it is necessary to employ a so-called "sliding pulser," which generates a series of pulses equally spaced in time but with an envelope which increases, then decreases, then increases and so on, linearly in time. An equal number of counts recorded in each channel serves to indicate that all channels have the same width.

The pulses supplied the differential discriminator should preferably have a nearly flat top lasting at least 0.5 μsec, and then decay rapidly to the base line. Such pulses are best obtained using a delay-line, pulse-shaping network with a highly stable feedback amplifier having a rise time of 0.5 μsec or longer.

The last portion of this series of review articles will include discussions of counting-rate meters, circuits for observing random pulses, delay-line pulse shaping, the generation of pulses, and stabilized power supplies.

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THE FOLLOWING is a preliminary list of titles, with authors, of declassified Canadian Atomic Energy Documents available from the National Research Council of Canada, Ottawa, Canada.

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gation of Fission Product Xenon and Fission Product Krypton. Thode, Graham. MX-129

Influence of a Large Black Cylinder Upon the Neutron Density in an Infinite Non-Capturing Medium. B. Davison. MT-135

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Concentration of Fe^{59} Activity by Szilard-Chalmers Separation. H. Dewhurst, N. Miller. CRC-351

NOTE: Recently completed exchange agreements have made possible the sale of copies of the first ninety-eight British Declassified Documents (see NUCLEONICS Vol. 2, No. 1) in microfilm or photostat form. They can be purchased from the Office of Technical Services, Dept. of Commerce, Washington 25, D. C. Abstracts of these documents, together with price and order number, have been published in *Bibliography of Scientific and Industrial Reports,* Vol. 8, No. 6 (Feb. 6, 1948), copy of which can be obtained from the Government Printing Office, Washington 25, D. C., for 25 cents.

Arrangements have also been made for the exchange of declassified documents between Canada and the United States. Announcement of this will be made at a future date.

Investigation of Reaction Mechanisms and Photosynthesis with Radiocarbon*

Discussion of fundamental chemistry underlying radiocarbon studies of photosynthesis and other complex organic rearrangements of biological interest—with bibliography

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ALTHOUGH one of the most obvious applications of isotopic carbon is in the study of the mechanism of a wide variety of organic transformations, relatively few such investigations have been made. Those that were made arose from the need for unequivocal methods of degradation of biochemical products or from the need to demonstrate the position of entering carbon atoms in a synthetic procedure during the course of the manufacture of some compounds required for biological study. Only in the past few months has the tool been used to study more complex organic rearrangements from the point of view of fundamental chemistry.

Oxidation of Propionic Acid

One of the first studies of a reaction mechanism arose from the need to degrade propionic acid resulting from bacterial fermentation (*1*). The method selected was oxidation by alkaline permanganate which gives quantitatively oxalate and carbon dioxide.

$$CH_3—CH_2—CO_2^- + 4MnO_4^- \cdots \rightarrow C_2O_4^= + CO_3^= + 4MnO_2 + OH^- + 2H_2O$$

The obvious presumption to make was that the oxalate originated from the alpha and beta carbon atoms, while the carbonate came from the carboxyl group. A test of this oxidation with synthetic carboxyl-labeled propionic acid, made by carbonating an ethyl Grignard with carbon dioxide, showed this not to be the case. The results (Table 1) clearly demonstrate that more of the oxalate arises from the carboxyl group and alpha carbon atom than from the methyl and alpha carbon atom (*2*).

Furthermore, the frequency of the alpha-beta rupture increases with increasing alkalinity. Similar experiments were performed on both alpha and beta hydroxy propionic acid which showed a ratio of alpha-beta rupture to alpha-carboxyl rupture of between 2 and 3, even at very high alkalinities (12 *N* NaOH). These experiments showed quite conclusively that the beta carbon atom is attacked before the three-carbon chain is broken, in at least one path of the oxidation; also, some of the propionic acid oxidation does not proceed through either alpha or beta hydroxy propionic acid.

The acid dichromate oxidation of propionic acid yields carbon dioxide and acetic acid in which the carbon dioxide originates entirely from the carboxyl group of the propionic acid (*1*). The acid oxidation of lactic acid is now being tested in view of the fact

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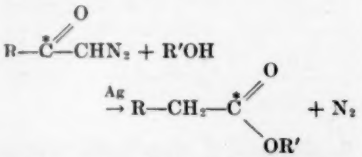
* From a paper presented at the Seventh International Solvay Congress of Chemistry in Brussels, September, 1947.

† A large part of the work reported here was done under the auspices of the Atomic Energy Commission in the Department of Chemistry and Radiation Laboratory, University of California, Berkeley, and represents the combined efforts of P. Yankwich, B. Tolbert, J. C. Reid, C. Heidelberger, A. A. Benson, and S. Aronoff.

that this reaction is very commonly used for the degradation of biologically formed lactate.

The Wolff Rearrangement

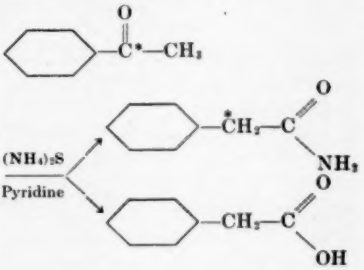
There are a considerable number of rearrangement reactions which seem to involve the breaking and making of new carbon bonds; one of these is the Wolff rearrangement.



This was one of the first of the rearrangement reactions to be studied with isotopic carbon. It was first done by Arnold (*3*) with C^{13} and has since been repeated at the University of California (*4*) with C^{14}. The results clearly indicated a shift of the R group from the carbonyl group to the diazomethane carbon atom.

The Willgerodt Reaction

In recent years the Willgerodt reaction has been extensively studied by kinetic and substitution methods (*4*). In view of its importance as a synthetic tool, we have examined this reaction in carbonyl-labeled acetophenone. A rather unusual result has appeared which is being further investigated. It may be summarized by the following reaction:

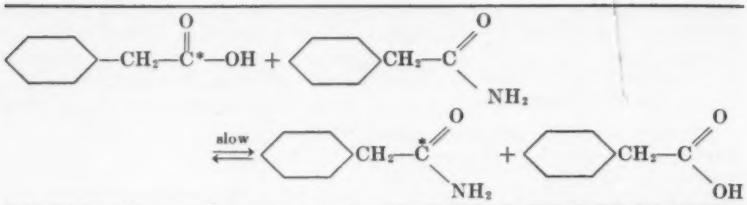


From this it is clear that the amide and the acid are formed by two different mechanisms. The formation of the amide does not involve the making or breaking of carbon bonds but rather is the result of a reduction and oxidation along the chain. The formation of the acid, on the other hand, must involve a carbon rearrangement. Furthermore, our ability to isolate both acid and amide from this reaction mixture having different radiocarbon distribution implies that the exchange reaction between acid and amide must be slow

TABLE 1

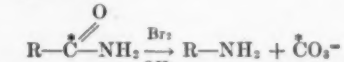
Permanganate Oxidation of Labeled Propionate

Experiment	*Concentration of* NaOH *moles/liter*	*Percent of* C* *in* $CO_3^=$		*Percent of* C* *in* $C_2O_4^=$		$\frac{\alpha C - \beta C \text{ rupture}}{\alpha C - COO^- \text{ rupture}}$
1	10^{-4}–10^{-5} (HCO_3^- Buffer)	28.2		71.8		
2	10^{-4}–10^{-5} (HCO_3^- Buffer)	27.6	28.9	72.4	71.1	
3	0.1	30.7		69.3		2.5
4	2	27.8		72.2		
5	2	30.4		69.6		
6	6	16.5		83.5		5.1
7	11	14.2	13.1	85.8	86.9	6.6
8	11	12.1		87.9		



under the conditions of the rearrangement shown above. This was tested in a separate experiment and confirmed.

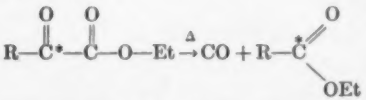
Another reaction of considerable importance in the degradation of acids is the Hoffman degradation with alkaline hypobromide.



The result could hardly be anything but the expected one and it was done incidental to the degradation work on the amide resulting from the Willgerodt reaction.

Decarbonylation of Alpha Keto-Esters

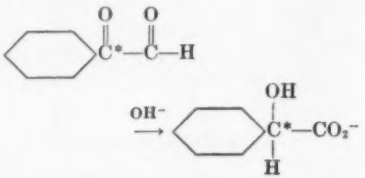
A reaction that is of considerable interest, not only as a synthetic method but also because of its close relationship to the biological decarboxylation of keto acids, is the loss of carbon monoxide when an alpha keto-ester is heated (*5*).



It would be of considerable importance to know something about the mechanism of this reaction especially with respect to which of the two possible carbons comes out as carbon monoxide. The reaction was tested by the thermal decomposition of carbonyl-labeled ethyl pyruvate. The carbon monoxide evolved contained no radioactivity. This indicates that it is the carbon of the carboxylate group which is eliminated even when that elimination involves the splitting up of the carboxyl group itself. A similar test is being performed on the free pyruvic acid. The results of this, however, can hardly be in question.

Rearrangement of Alpha Keto-Aldehyde

The last reaction involves the rearrangement of an alpha keto-aldehyde (*6*).



The alpha-labeled phenyl glyoxal was rearranged in alkali to produce mandelic acid, the label remaining on the alpha carbon atom. This is, therefore, also the result of a rearrangement of hydrogen atoms only, that is, an oxidation and reduction along the chain similar to that observed in the Willgerodt rearrangement for the formation of amides.

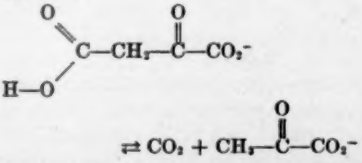
Applications in Biology

Although most of the so-far published work involving isotopic carbon in biology has been in the field of bacterial and animal metabolism, this discussion will be confined to the briefest review of the most definitely established results serving only as a backgrcund for the more extensive discussion of photo-

synthesis which follows. For more detailed examinaton of this subject, reference should be made to several excellent reviews already published (*7, 8, 9, 10, 11*).

Probably the first definite impact which the use of isotopic carbon made on biochemistry was the establishment of the fact that carbon dioxide is not merely a terminal metabolic waste product, but actually plays a part itself in the various metabolic cycles that are being discovered. This was first shown by the simple experiment of exposing a variety of biological preparations—bacteria, yeasts, and minced animal tissues of various types—to isotopically marked carbon dioxide and then demonstrating that this carbon dioxide had actually been incorporated into the organic compounds present in the biological material used.

More recently, the particular compounds into which the carbon dioxide has been incorporated have been determined as well as the particular position occupied by the carbon atom. These compounds have generally turned out to be the various acids involved in the di- and tri-carboxylic cycles, going all the way to glycogen in the case of liver. The point of entry of carbon dioxide was presumed to be the beta carboxylation of pyruvic acid to give oxalacetic acid. This is known as the Wood-Werkman reaction since it was first proposed by them in connection with the formation of succinic acid by propionic acid bacteria dissimulating glycerin.



This has since been shown to be a clearly reversible reaction using cell-free extracts of various types as a source of the beta-carboxylase enzyme in the presence of ATP. The experiment was done simply by allowing the enzyme to act on oxalacetic acid in the presence of isotopic carbon dioxide and then demonstrating the presence of the isotope in the remaining oxalacetic acid. The scheme shown in Fig. 1 can then be set up to account not only for the presence of the isotopic carbon atoms in the intermediate acids, but also for the particular positions which they occupy in these acids and in the glycogen form. See the next page.

Experiments of this type are being extended using laboratory-synthesized intermediates containing the isotope in various positions and isolating and degrading the proposed intermediates. For example, carboxyl-labeled acetate, carboxyl-labeled lactate, and alpha and beta-labeled lactate have all been used and their incorporation into intermediates of the di- and tri-carboxylic cycles have been demonstrated. As this work progresses and the various enzymes involved are isolated and their reactions demonstrated, we can look forward to a rapidly unfolding picture of interrelationships of fat, protein and carbohydrate metabolism. It is already known, for instance, that many intermediates are common to the synthesis and degradation of all three types of material.

Isotopic carbon has been used to determine the source or fate of such other special compounds of biological interest as urea, uric acid, tyrosine, phenylalanine, and the porphyrins, and work is now progressing on studies of the metabolism of the sterols, vitamins, hormones, etc. Still another type of study in progress is the examination of the fate of many compounds not normally present in the organism, such as synthetic drugs, carcinogens, and the like.

The biological precursors of uric acid carbon (*12, 13, 14*) were determined by

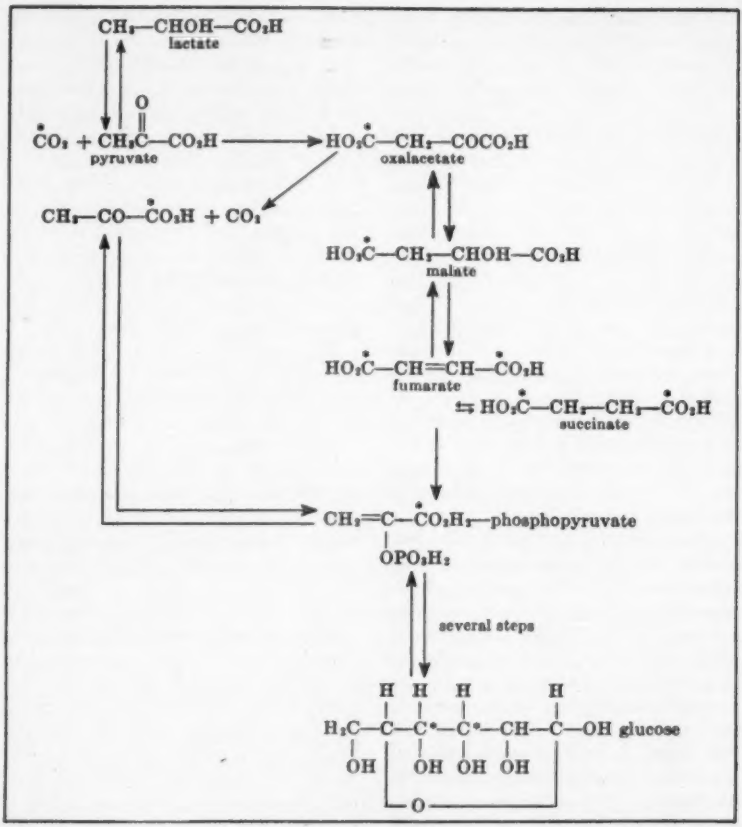
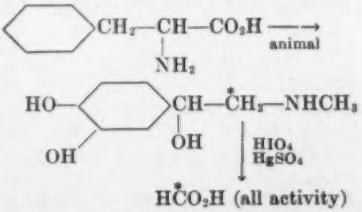


FIG. 1. Paths by which isotopic CO_2 and lactate may be incorporated into glycogen and its intermediates

administering labeled compounds to pigeons. The compounds used were carbon dioxide, carboxyl-labeled acetate, carboxyl-labeled lactate, alpha and beta-labeled lactate, carboxyl-labeled glycine, nitrogen-labeled glycine and formic acid. The excreted uric acid was isolated and degraded. The results are summarized in Fig. 2.

By feeding labeled phenylalanine (*15*), it has been shown that adrenaline is formed from it directly by decarboxylation and oxidation without rupture of the ring side chain structure as shown in the following reaction:



In another set of experiments, beta-labeled tyrosine (*16*) was injected into

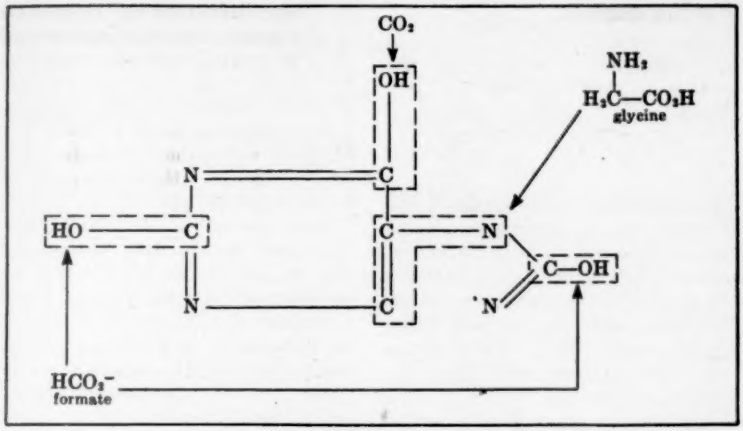


FIG. 2

the tail vein of melanomous mice which were then subjected to an anatomical fractionation after varying periods of time. The highest specific activities were found in the intestinal mucosa, the adrenals, the thyroid, and the melanoma. The latter three findings were to be expected since tyrosine is a precursor of adrenaline, thyroxine and melanin. The finding in the intestinal mucosa seems to indicate an active protein-synthesizing system in this organ, a result comparable to that obtained using S^{35}-labeled methionine (*17*). It should be pointed out that tyrosine administered in this way is very rapidly metabolized, 20% of the radioactivity appearing in the expired carbon dioxide in the first twelve hours.

Another problem of considerable interest showing promise of being solved by these methods is the fate of carcinogenic hydrocarbons. Heretofore, only a small percentage of the administered carcinogen (dibenzanthracene) has been accounted for by the ordinary analytical methods, such as straight chemical analysis or spectroscopic analysis. These, of course, were limited to a recognition of the condensed ring system and could not detect more extensive degradations.

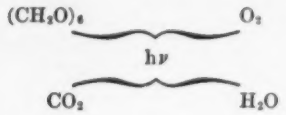
Recently 9,10-labeled dibenzanthracene was synthesized; its fate, following administration to mice, is now being examined (*18*). It has already been discovered, upon administration by injection of an aqueous colloid, that a considerable fraction (50%) is rapidly excreted through the bile. The feces of animals injected intraperitoneally with the carcinogen in tricaprylin have been examined and, of the radioactivity in the feces, some 80% has been found to be water-soluble. This is indicative of an extensive degradation into water-soluble aromatic acids, since the methods of fractionation rule out conjugation with water-solubilizing substances.

Photosynthesis

Photosynthesis is probably one of the most easily defined of present-day biochemical problems and most difficult of solution. It is apparent that a most involved kind of physics, chemistry, and biology must be concerned with its solution (*19, 20, 21*).

The over-all problems involved can be most readily appreciated in terms

of this diagram:



The green plant is able to take carbon, hydrogen, and oxygen in the lowest energy forms (as carbon dioxide and water), together with electromagnetic energy in the form of visible light, and convert this system into compounds of higher energy content, that is, gaseous oxygen and reduced carbon, generally in the form of carbohydrate.

The questions may then be asked: By what path is the quantum of light primarily converted into chemical energy, and what is the path taken by the three elements, carbon, hydrogen, and oxygen (and presumably the other elements constituting the living organism) to pass from their initial low-energy condition into their final high-energy states? It is obvious that, at least for the latter part of the problem, isotopic tracers of carbon, hydrogen, and oxygen provide the method par excellence of mapping what appears to be a very intricate network of paths.

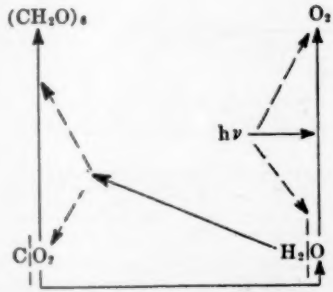
Isotopic carbon (and in some experiments, O^{18}) has already provided not only considerable information about the nature of the intermediate steps involved in the transformations of carbon dioxide and water, but also some clues as to the nature of the primary action of the light conversion. Earliest of this work is that of Ruben and coworkers using C^{11} (*22*, *23*, *24*, *25*). They were able to confirm the suggestions arising out of the flashing-light experiments that there existed a preliminary fixation of carbon dioxide not directly connected with the act of light absorption itself and that this reaction was at least partially reversible. Furthermore, by using isotopic oxygen, they demonstrated (*26*) that the gaseous oxygen produced in photosynthesis had its origin in the water molecule rather than in the oxygen of the carbon dioxide molecule. They were unable, however, to characteristize the compounds into which the carbon dioxide was incorporated in the dark, primarily because of the short half-life of C^{11}.

All of the work so far described was done prior to the war. During the war Dr. Ruben lost his life and the work ceased. A major activity of the University of California laboratory is the continuation and extension of the work on photosynthesis using C^{14}, with which tool the experimenters are not inconvenienced because of a short half-life. One of the first results to come from this laboratory was the demonstration of the ability, at least of chlorella, to store reducing power during illumination in the absence of carbon dioxide.

The experiment was performed as follows: A sample of actively photosynthesizing fresh chlorella was divided into two parts. One part was kept in the dark in the presence of normal carbon dioxide, while the other part was illuminated in the absence of carbon dioxide, both for a period of about one hour. The two samples of chlorella were then exposed immediately (within a minute after the cessation of the illumination) to the same radioactive carbon dioxide in the dark. The sample which had been preilluminated was able to fix as much as ten times the amount of carbon dioxide as the one which had been kept in the dark. Furthermore, upon analysis of the fixed carbon in the sugar fractions of both samples, it was found that the dark sample had very little radioactivity (less than 0.1%) in the sugar fraction (glucose). In the preilluminated sample, as much as 2% of the total activity was found in the sugar fraction. It was thus apparent

not only that reducing power is stored during illumination in the absence of substrate but that this reducing power is capable of carrying subsequently administered carbon dioxide up to the state of carbohydrate.

A number of items on the originally blank sheet with which the problem of photosynthesis was defined can now be filled in:



It thus appears that the line representing the path to molecular oxygen has its origin in water and that the oxygen originally present in carbon dioxide must first pass through water on its way to gaseous oxygen. Furthermore, it is now certain that the primary action of light absorption and its initial conversion into some form of chemical energy does not take place along the carbon dioxide-carbohydrate line. This confirms in a particular way the very broad generalizations made by Van Niel (*19*). He indicated that the function of light is to make available active hydrogen from water which could then be used to reduce carbon dioxide in the same way as other forms of energy may be used to reduce compounds in nonphotosynthetic organisms. Whether the photochemical reaction directly involves water or some complex of it at very nearly that energy level, or whether the photochemical reaction operates at some intermediate energy level, is still a moot question. In terms of the chart, the point of entry of the photon along the water-oxygen line is unknown.

A more detailed analysis of the fate of the dark-fixed carbon dioxide is now in progress. Table 2 gives the information as we have it to date on the distribution by compounds of this dark-fixed carbon dioxide in both preilluminated and dark-pretreated chlo-

Table 2

Dark Fixation of CO_2 by Chlorella (*27*)

Preparation No.	I	II	III
Pretreatment	CO_2 in dark	Light in absence of CO_2	
Total (relative units)	1	5.5	10
Succinic acid }	70%	6%	0.3%
Fumaric acid } extracted by ether from pH 1	3%	1%	0.3%
Malic acid }	—	6%	1.75%
Cationic substances	15%	30%	20%
(Alanine)		(18%)	(7%)
Anionic substances	9%	10%	9%
Neutral	<0.1%	1.5%	8%
(sugars and glucose)			(4%)
Unidentified (extractable by ether from pH 6)	2%	6%	0.2%
Unidentified (extractable by ether from pH 1)	—	25%	2.7%
Lost (unidentified—probably alpha and beta-keto acids)	—	—	50%

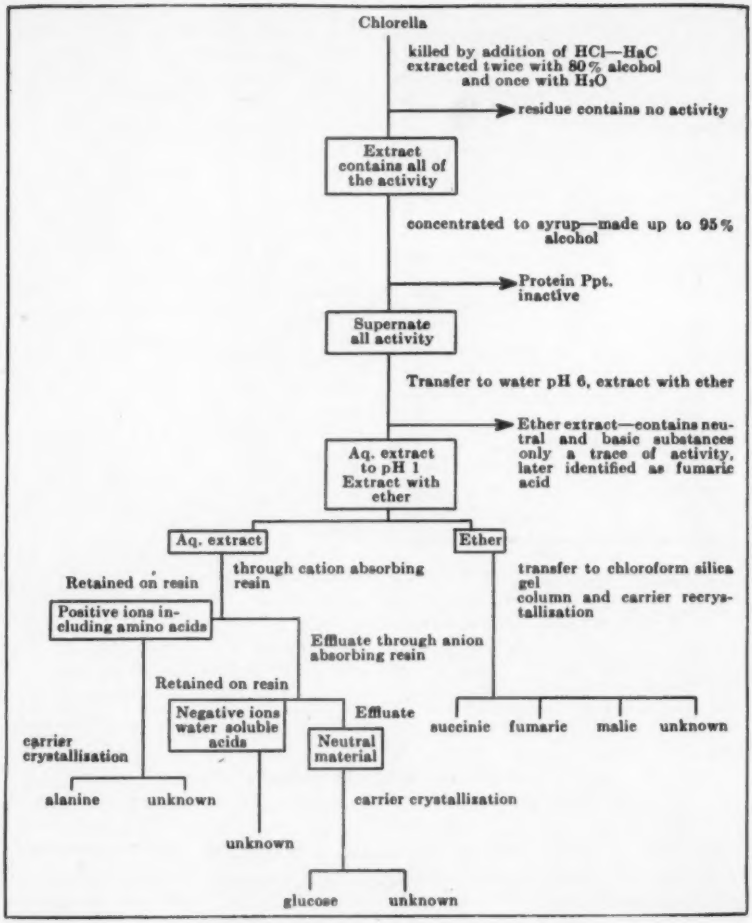


FIG. 3. Method of fractionation (*28*)

rella. Fig. 3 shows the method of separation.

It is evident from these charts that there are still many gaps to be filled and some of them are very likely most important to an understanding of the processes involved. Beyond this, three of the isolated substances have been degraded and their radiocarbon distribution determined. The first of these is the succinic acid. This was degraded by an unequivocal series of reactions which enabled specification of percentage of radioactivity to be found in the carboxyl and methylene groups. See Fig. 4.

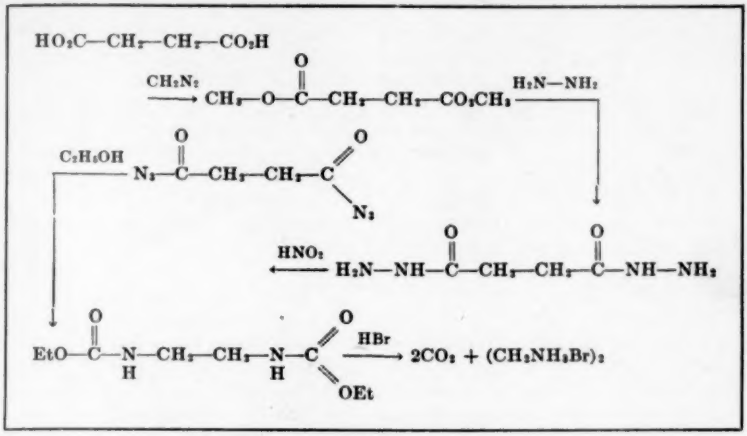


FIG. 4

The succinic acid from the dark pretreated algae (I) contained no detectable amount of activity in the methylene groups, whereas that from the light pretreated (III) had 2% of its activity in the methylene groups. The next compound to be degraded was the alanine. It was treated as shown in the following reaction scheme (*29*).

$$CH_3-\underset{\displaystyle NH_2}{\underset{|}{CH}}-CO_2H \xrightarrow[2)\ \text{Dichromate}]{1)\ \text{Ninhydrin}} CH_3CO_2H + CO_2$$

The results although not yet as unequivocal as those with the succinic acid seem to indicate 90–95% of the activity in the carboxyl group with 5–10% in the remaining fragment.* The glucose derived from this dark fixation has not itself been degraded, but some glucose prepared in a short photosynthetic experiment has been degraded according to the scheme in Fig. 5 (*30, 31*).

Relative amounts of radioactivity found in the three pairs of carbon atoms were as 0.6:1.0:2.1 for (1,6):(2,5):(3,4). This photosynthetic glucose represented some 35% of all the radiocarbon incorporated into the plant (barley leaves) during the course of a one-hour photosynthesis (*32*).

Before the significance for photosynthesis of the particular compounds into which the radiocarbon has been fixed can be described, it is necessary to arrive at some answer to the question of the possible relationship of these compounds to the respiration of the algae. Undoubtedly there exists in the algae the same group of respiratory enzymes that has been found in animal tissues. It is conceivable, then, that the fixation of carbon in the acids of the dicarboxylic cycle may have been achieved by virtue of reversibility of the reactions of this cycle in much the same way that fixation into these compounds has been demonstrated in liver and muscle extracts and in rat livers.

The first and most powerful argument that can be presented at this time is the profound effect of preillumination on the nature of the fixed carbon. The absence of any fixation in glucose in the predark treated algae and its

* This is most likely in the alpha carbon atom although experiments to determine this have not yet been completed.

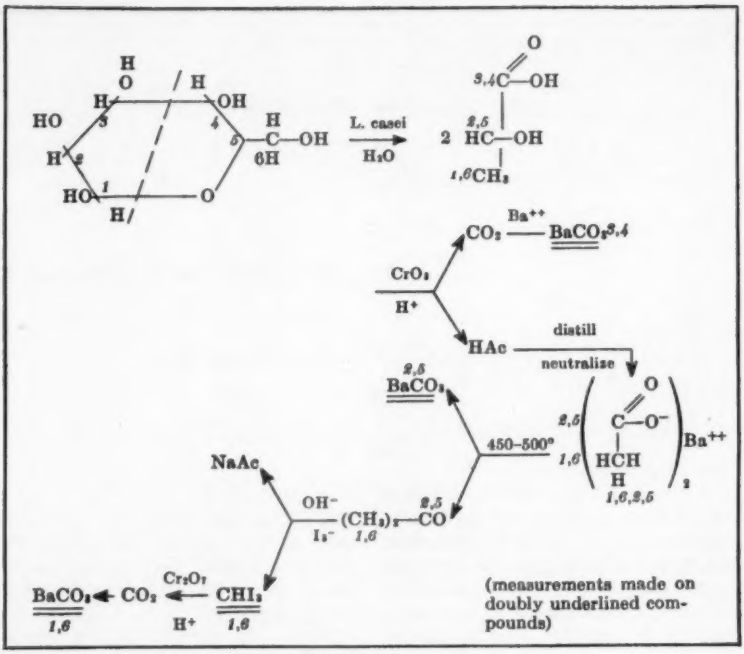

L. casei
H₂O
3,4
2,5
1,6CH₃
Ba++
CO₂
BaCO₃3,4
CrO₃
H+
HAc
distill
neutralize
2,5
BaCO₃
450–500°
1,6
1,6,2,5
NaAc
OH⁻
I₂⁻
(CH₃)₂—CO
Cr₂O₇
H+
CHI₃
1,6
BaCO₃
CO₂
(measurements made on doubly underlined compounds)

FIG. 5

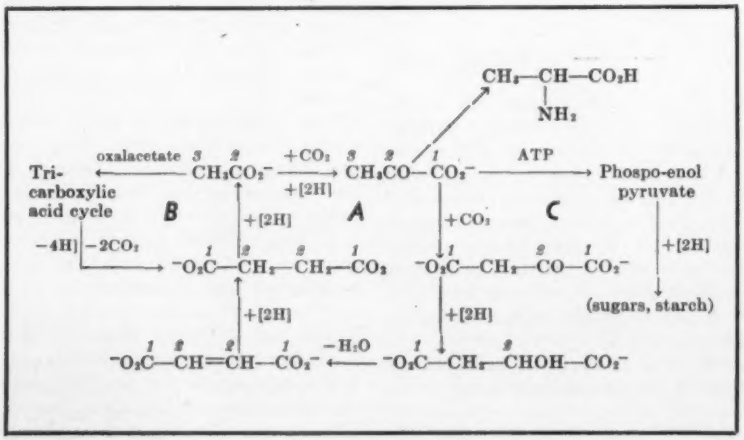

oxalacetate
Tri-carboxylic acid cycle
B
A
C
ATP
Phospo-enol pyruvate
+[2H]
−4H]
−2CO₂
+CO₂
(sugars, starch)
−H₂O

FIG. 6

presence to a very considerable extent in the preilluminated algae, both under anaerobic conditions, seems to indicate that we are indeed dealing with the photosynthetic intermediates and not merely with the respiratory intermediates. If the latter is the case, one might expect at least some fixation of carbon dioxide in the glucose from the predark treated algae—a situation which actually obtains for *in vivo* experiments with animals with certain isolated organs and in liver slices. It may well be that all or part of the succinic acid found in the predark treated algae is the result of the reversal of the respiratory reactions. However, since most of the fixed carbon in the preilluminated experiments is to be found in other forms, it seems reasonable to suppose that these are indeed the intermediates in the photosynthetic reduction of carbon dioxide.

It is possible to account for the results as they now stand by making use of a group of reactions each of which has been demonstrated previously either with animal tissue or bacteria (*11*). These constitute only an allowable scheme, most of which has been previously speculated upon. Undoubtedly, there are other allowable schemes which would account for the meager results so far available (*28*), but that shown in Fig. 6 can be used as a working hypothesis for the conception of new experiments until such time as the data require its modification or rejection.

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Selection of Radioautographic Technique for Problems in Biology

Determining factors include characteristics of radioisotope involved, such as physical and chemical properties, and type of radiation emitted. Desirability of using thin tissue sections and methods of aligning tissue and autograph are also discussed

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IT IS WELL KNOWN that ionizing radiation will affect photographic emulsions. This is one of the oldest methods of demonstrating radioactivity. The photographic method is not nearly as quantitative as the electrometer or the Geiger counter, but offers the advantage of localizing the source of radiation more minutely. A tissue, or organ, containing a radioactive material in just a small portion of it may be placed close to a photographic plate to produce, eventually and upon development, a darkening of the emulsion only in the region that was adjacent to the radioactive portion. Such an image is known as a "radioautograph," "autoradiograph," or (more simply) "autograph."

The optimum conditions for making a radioautograph are those which will detect the presence of even small amounts of radioactivity, localize it accurately, and show the amount present relative to that in adjacent regions. Several developments in the field of radioautography have been made recently and many variations are available from which one may select the technique that is best for a given condition. It is the purpose of this discussion to mention, briefly, some of the factors one may consider in selecting the technique best fitted for his particular situation.

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Properties of Isotope Used

The investigator should consider physical as well as chemical properties of the radioisotope he wishes to use. For example, the half-life of the isotope is important in determining how quickly the preparation must be made and how long the exposure should be. The usual time required to prepare histologic sections can be shortened by use of (1) only very small pieces of tissue, (2) agitation and gentle heat during fixation, dehydration and embedding, and (3) suction to remove entrapped air. One can usually determine by Geiger counter measurement whether a long or short exposure will be required. In addition, if a few preparations are made on sensitive emulsion (such as dental X-ray film), one can develop these after various amounts of exposure and determine when the exposure of the slower but more critical preparations should be terminated. Exposures beyond one or two half-lives are usually not very satisfactory. This is so because of accumulated effects of ageing, exposure to stray radiation, and possible fading of the

radiation effect at room temperature.

The type of emitted radiation is a factor in determining the proper emulsion to use. Those available are (1) the usual ones designed for visible light, (2) the "X-ray" emulsions, (3) the "spectroscopic plates," and (4) the special "particle plates." Most of the isotopes of elements usually found in organisms have a relatively limited half-life and emit gamma and (or) beta radiation. The usual X-ray emulsions are very sensitive to these radiations, but the grain is large and irregular. The spectroscopic and particle plates give much finer localization but they are less sensitive. The usual lantern slide emulsion offers a compromise since it is not as sensitive as the X-ray film (but is more so than the spectroscopic or alpha particle plates) and the resolution obtained with it is satisfactory for most purposes. The special fine grain plates are excellent for tissues containing large amounts of beta activity. Of course, the special alpha particle plates offer the emulsion of choice for elements emitting this type of radiation.

Another of the properties to consider is the solubility of the contained radioactive element. If it is relatively insoluble in the solutions employed in the usual microtechnique procedures, then the problem is greatly simplified. For example, one of the radioisotopes most widely used in radioautography is I^{131} incorporated into organic molecules by the thyroid. It is possible to preserve the gland in the usual fixitives, such as formalin or Bouin's solution, without dissolving the contained radioelement. The tissue may then be dehydrated in alcohols, embedded in paraffin and sectioned. P^{32} on the other hand is lost rapidly in acid fixitives and one must use neutral formalin, alcohol or acetone for this process. Loss of soluble material may also be reduced by freezing the tissue, and by keeping it frozen during sectioning, and during exposure of the photographic plate. The sections are necessarily thick, and the resulting autographs do not give very precise localization. Thickness of tissue section is not such a handicap if the emitted radiation is of very soft beta or alpha particles. In such a case, the radiation from deeper regions are absorbed within the tissue and only the particles arising from near the surface are free to affect the photographic plate.

Thin Tissue Sections

It is usually desirable to cut tissue sections as thin as possible (5–10μ) so that the autograph will be sharply outlined. However, in some instances the radiation intensity will be low and it will be necessary to cut thicker sections in order to produce an autograph. The amount of the radioisotope present influences the choice of photographic emulsion. If the radiation intensity is weak then it will be necessary to employ a very sensitive emulsion. If the radiation intensity is strong then one can sacrifice sensitivity (if it is not important to obtain results quickly) and use one of the fine-grain emulsions. The fine-grain emulsions give better resolution and permit study at high magnification. The medium contrast emulsion of a 2 in. $\times$ 2 in. lantern slide plate offers a good compromise between maximum sensitivity and maximum resolution or definition.

If one leaves an exposed plate in the photographic developer until all affected grains of silver bromide have been reduced to free silver, then a considerable background is usually observed. This background or general darkening of the emulsion is more evident with low radiation intensity where the exposure time has necessarily been prolonged. It is of course accentuated if exposed to light, heat, or stray ionizing radiation. Strong radiation sources produce sharper images as one can minimize the background by using a

short exposure and short development time. With an adequate intensity, it will be found that the background will be less evident if one lengthens the exposure time so that the development time can be reduced. If the autograph itself is heavy enough, the contrast can be improved by reducing, generally with such agents as potassium permanganate, etc.

It has been mentioned above that (due to rapid spread of radiation from its source) an autograph becomes more diffuse the greater the thickness of the tissue and the emulsion. Likewise, it becomes more diffuse the greater the distance between the tissue and the emulsion. Therefore, it is essential to hold the tissue firmly against the emulsion during exposure.

Alignment Methods

Three methods of aligning the tissue and autograph are shown in Fig. 1. The first method is shown in Figs. 1*a*, *b* and *c*. The tissue section is mounted on the usual microscope slide and this is held face down against the photographic emulsion during the exposure period (1*a*). Before these are placed together,

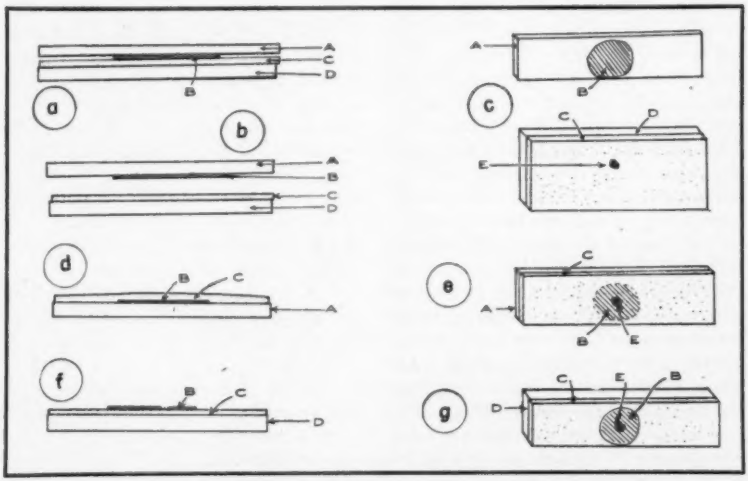

FIG. 1. Diagrams illustrating three methods of preparing radioautographs.

METHOD 1.

a. (Side view). Microscope slide (A) with tissue (B) attached is temporarily placed against photographic emulsion (C) during exposure; (D) is the photographic plate which bears the emulsion.

b. After the exposure the slide bearing this tissue is separated from the photographic plate.

c. (Face view). After development, the autograph (E) appears in the emulsion. Reference marks previously made on (A) and (C) aid in matching the two to give a general idea as to the position of (E) in the tissue.

METHOD 2.

d. Preparation made by coating the tissue with melted emulsion removed from a photographic plate.

e. Face view of coated tissue preparation after exposure and development.

METHOD 3.

f. Preparation with tissue mounted directly on the photographic emulsion.

g. Face view of tissue-autograph preparation after exposure and development.

a reference mark is placed at one end of the photographic plate. This may consist of three dots or any asymmetrical figure. Then, after the slide has been inverted on the photographic plate, this reference mark is traced on the back side of the microscope slide. After the exposure, the slide with the tissue is separated from the photographic plate (1*b*). The tissue section is then stained, cleared and mounted for histologic study, and the photographic plate is developed to bring out the autograph (1*c*).

The region of the tissue which produced the autograph can usually be determined approximately by inspection. In addition, the slide may again be inverted on the photographic plate so that the two reference marks correspond. One may then study the two together under low magnification by first focussing on the tissue and then on the autograph without changing the position of either. At high magnification it will be noted that alignment is not exact and precise localization of the autograph is very difficult. Two methods have been devised to keep the alignment of tissue and autograph the same throughout exposure and development. In one of these, the tissue section is coated with liquified emulsion removed from a photographic plate (1*d*). After exposure and drying of the emulsion, the entire preparation is placed into photographic developer until the autograph is evident. It is then placed in hypo to stop development and is later washed and dried. This is the usual process for development of photographic plates. The entire preparation is then put through the stains, dehydrating and clearing agents, and mounted in balsam under a cover glass. The advantages of this method are that (1) the emulsion and tissue are close together, which results in minimal scatter, (2) the alignment is automatic, and localization of radioactive elements is more accurate. Some difficulties are (1) liquifying and recoating the emulsion increases the background fog, (2) the emulsion coat is less uniform in thickness and (3) differential staining of the tissue is difficult. This latter problem may be alleviated by staining, dehydrating, clearing and mounting the tissue in a medium impervious to water, before the photographic emulsion is coated over the tissue.* This will probably be an improvement but requires more time before the exposure can be made and it also increases the distance between the tissue and the emulsion. This method has also been modified by using stripping film instead of the liquid emulsion.† This reduces the distortion produced by alternately expanding and contracting free emulsion.

A third method reduces the distortion, etc. of the emulsion even more. This consists of floating the tissue section on to the photographic emulsion (Fig. 1*f*), in the dark room, and in leaving the tissue so mounted during the exposure, development of the autograph, and staining, etc. The chief difficulty is in getting a good differential staining of the tissue. Satisfactory, though not perfect, staining may be obtained by using slightly longer periods

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* See footnote on p. 2 of ref. *18*. Also personal communication from Drs. C. P. Leblond, W. L. Percival and J. Gross, McGill University. (Manuscript submitted to *Proc. Soc. Exp. Biol. Med.* for publication.)

† Personal communication from Drs. K. M. Endicott and F. A. Clarke, National Institute of Health (manuscript in preparation). Details of method follow: Prepare paraffin section. Deparaffinize. Stain. Dehydrate with acetone. Flood with Duco cement. Dilute 1:20 with ethyl acetate. Pour off the excess cement and place the stripping film, cellulose acetate side down, on the section. The cement sets rapidly. After appropriate exposure, the preparation is carried through developer, hypo, and wash. During this process it usually comes off the slide and is dried between blotters to keep it flat. It is then placed in a shallow flat container of cedar oil, is transferred to xylol, and is then placed on a few drops of xylene clarite on a microscope slide, is covered with xylene clarite, and finally with a cover slip.

FIG. 2. Photomicrograph of tissue-autograph preparation (× 700) of a small region of thyroid containing I^{131}. The plane of focus is just below that of the tissue. Sections were cut at 5μ and mounted on an Eastman 2 × 2 inch medium contrast lantern slide. Hematoxylin and eosin stain. Note heavy concentration of grains of reduced silver (indicating presence of radioactivity) in upper follicle, slight amount in follicle to the left and none in lower two. (T. C. Evans, "Preparation of Radioautographs of Thyroid Tumors for Study at High Magnification," *Radiology* **49**, 206–213, 1947.)

in the stains and other solutions and by washing thoroughly. The resolution is good and such preparations may be studied under high power. An example is shown in Fig. 2. This photomicrograph is of a section of thyroid tissue containing radioiodine. The same method may be used for autographs with alpha emitters (Fig. 3). The resolution with alpha particles is very good because of the short range in emulsion of the radiation. By using special particle plates, individual tracks of the particles may be seen. Under certain conditions the starting point of a particle is evident. This gives the maximum resolution obtainable at present.

Summary of Factors Involved

In summary, it may be stated that selection of the proper technique depends upon the particular situation and whether the factor most desired is (1) greatest sensitivity, (2) greatest resolution or (3) greatest range of response. The means of obtaining factor (1) are (*a*) use of very sensitive film or plate (thick emulsion with large photosensitive grain), (*b*) reduction of distance

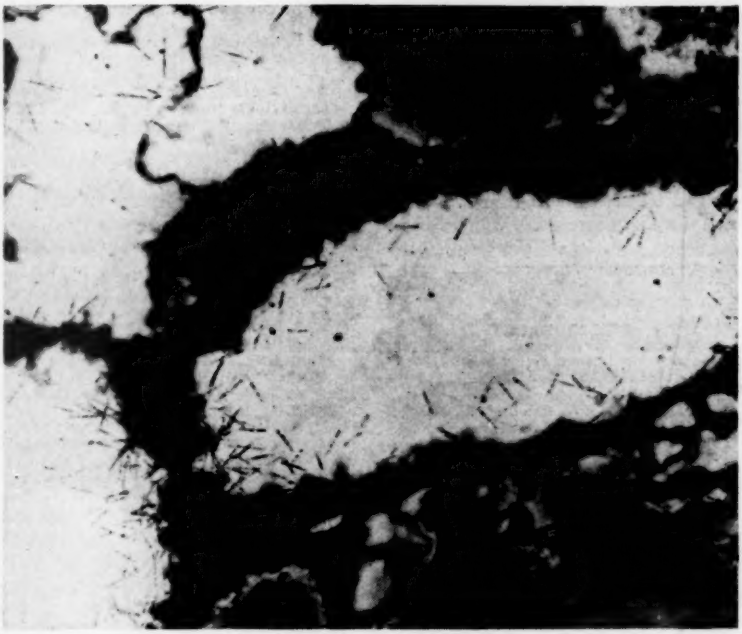

FIG. 3. A photomicrograph (× 210) of lung tissue containing an alpha-emitting substance. Mounted on Eastman particle emulsion. Alpha tracks may be seen emerging from lining epithelium of bronchii and some of the alveoli. (Dorothy J. Axelrod and J. G. Hamilton, "The Radioautographic Technique," *U. S. Naval Bulletin*, 48, special issue, in press.)

between source of radiation and emulsion to a minimum, (*c*) prolonging of exposure time, and (*d*) reducing the time of preparation (*i.e.*, before exposure) to a minimum. Means of obtaining factor (2) are (*a*) use of emulsion designed for type of radiation employed, especially if radiation is "soft" and densely ionizing, (*b*) use of thin emulsion with small grain size, (*c*) reducing distance between tissue and emulsion to minimum, (*d*) over-exposure and under development, and (*e*) reducing background by use of proper chemicals. Means of obtaining factor (3) are (*a*) use of thick emulsion, (*b*) complete development and (*c*) comparison of different autographs of identical sections that have been exposed for different lengths of time.

This discussion serves only as a general introduction to a study of some of the newer techniques of radioautography and one should consult the following references for details. The physical principles are dealt with in papers (*6*) and (*19*). For a description of the coated tissue technique, one should read (*4*) and (*9*); papers (*10*), (*11*), and (*12*) deal with the tissue-on-emulsion method. References (*7*) and (*15*) describe methods of autography in dealing with soluble materials. For papers concerned with autography of

bone one should read (*1*), (*5*), and (*8*). Papers (*2*) and (*18*) demonstrate autography of labelled compounds. For autographs with radioiodine one should read (*11*), (*12*), (*14*), (*16*), (*17*), and (*20*). (*5*) and (*13*) are concerned with radiocarbon, and (*6*) and (*10*) with alpha-emitters. Reference is made to (*3*) and (*18*) for a more complete bibliography and to a review which will be published shortly in this journal by Dr. A. Gorbman.

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Naphthalene Counters for Beta and Gamma Rays

IN A REPORT received recently in this country, H. Kallman describes some work on radiation detectors using scintillations produced in various materials. Dr. Kallman's work was carried out in the Kaiser Wilhelm Institut for Physical Chemistry. His results with conventional inorganic phosphors like zinc sulphide, calcium tungstate, etc., parallel closely the work carried out in this country, at the same time, particularly by the Princeton and Westinghouse groups.* He finds that while these phosphors are very satisfactory for the detection of alpha particles and —presumably—other highly ionizing rays, the fact that they are opaque to their fluorescent radiation proves a serious handicap in their application to beta and gamma rays. Since the light can escape only from layers about 10 mg/cm² thick, only a small fraction of the total available energy of the beta rays or secondary electrons can be converted into light in a place from which it can reach the sensitive cathode of the photomultiplier.

On the other hand certain organic phosphors, particularly naphthalene, are very transparent to their fluorescent radiation and Kallman found that all of the light produced in layers as thick as one centimeter can still escape and reach the photosurface. Thus very large pulses can be obtained from the absorption of beta and gamma rays in naphthalene. Even so, the pulses caused by slow electrons may be masked by the dark current fluctuations

* NUCLEONICS 1, No. 3, 58 (1947).

of the multiplier tube. It is found that when the multiplier is cooled to about −40° C the dark current is reduced sufficiently to count most of the electrons ordinarily encountered in radioactive decays. Because of the possibility of using large blocks of naphthalene, very high efficiency for counting gamma rays can be obtained. In addition to this, it is found that the scintillating pulses from this material are extremely fast, much more so than those from conventional phosphors. On the other hand, naphthalene seems to be insensitive to alpha particles.

After receipt of Kallman's report, work carried out at the Massachusetts Institute of Technology by Deutsch confirmed Kallman's results and showed that the standard 931-A photomultiplier tube is suitable for use with naphthalene. It was found that the pulses are faster than 10^{-7} seconds, which is important in coincidence experiments. By the use of naphthalene blocks covering the entire sensitive area of the tube to a thickness of about ½ inch an efficiency of about 20 percent for gamma rays was obtained. This is twenty times greater than can be reached with conventional Geiger-Müller counters. The new detectors have already been applied to certain coincidence experiments with great success. Under the conditions of these experiments, they permitted an increase by a factor of several hundred in the rate of obtaining data as compared with the previous methods of using G-M counters.

The dark current of the multiplier tubes prevents application to many routine counting procedures at room temperature. Following a suggestion of Kallman, it was found that by placing the naphthalene between two multiplier tubes connected in coincidence, the number of dark current pulses could be reduced considerably, permitting high efficiency counting with low background, even at room temperature.

Beta and gamma ray energies can be measured by observation of the pulse height distribution from the multiplier tube. The energy discrimination thus obtained is at least as good as that of good absorption experiments without the great loss in intensity usually imposed by the geometrical conditions of absorption measurements. As in the case of inorganic phosphors the naphthalene counters have no "dead time" and can be used for direct current measurements at high radiation levels.

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CORRECTION—"PRECIPITRON"

In "General Rules and Procedures Concerning Radioactive Hazards," NUCLEONICS, December, 1948, page 67, the word "precipitron" was used as a generic term. "Precipitron" is the registered trade-mark of the Westinghouse Electric Corporation used on electrostatic air cleaners and accessories therefor.

The Special Theory of Relativity in Nucleonics

THE PURPOSE of this article is to describe the relationship of the special theory of relativity to the general field of physics and to discuss some applications of this theory in the field of nucleonics. These include some related to the mass-energy equivalence theorem, two special cases of motion of a charged particle in an electromagnetic field, and the role of relativity in measurements of the decay of fast cosmic mesons. These applications should serve to emphasize the necessity for an understanding of the special theory in the nuclear domain.

In seeking a description of the universe, the modern physicist defines his sphere of operations by application of the operational method (*1*). According to this procedure, *physical concepts*, such as the mass, length, charge, temperature, etc., of a body are not viewed as things whose nature is "intuitively understood," but are defined as the results of particular sequences of manipulations and calculations which can, conceptually at least, be carried out in the laboratory. The question of the "nature" of these concepts simply does not arise. *Physical laws* are statements describing certain relationships among operationally defined physical quantities which seem invariably to hold when certain experiments are performed. The role of *theory* is to provide, on the basis of a few *hypotheses*, a unified, formal description of the outcome of as large a group of experiments as possible and to suggest new experiments which may lead to new physical laws. The ultimate goal appears to be the development of a single theory which can correlate in a logical way the results of all conceivable experiments involving any set of operationally defined physical quantities.

In any experiment, one must guard against the intrusion of subjective or non-operationally defined concepts. This is often very difficult, particularly in mechanics, because all of us have strong intuitive feelings about "length" and "time" due in part to the inadequacy of language as a means of communicating descriptions of our experiences to each other and in part to the limited nature of our daily experiences. We are not likely to believe, for example, that the "length of an object" is in any way dependent upon its state of motion with respect to an observer or that the "time interval between the occurrence of two events" depends in any way upon the relative state of motion of the person observing the events. Nevertheless, according to the special relativity theory, both statements are true (*2*).

An aircraft traveling at 800 miles per hr with respect to the earth would be expected to appear, as a result of measurement in a carefully prescribed way, about 10^{-10} in. shorter to a ground observer than it would appear to an observer in the aircraft, assuming that it was 30 ft long as measured by the latter observer. The "true" length of the aircraft is without significance. Further, if two successive lightning bolts strike the same spot of ground ahead of the aircraft in such a way that the ground observer, after making some very precise comparisons with a clock, reports a time interval between them close to 25 sec, the aircraft observer, making similar measurements on the same events would be expected to report an interval shorter by about 10^{-8}

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μsec. The "true" time interval is again without significance. The comparisons with a specified clock, described above, constitute the laboratory manipulations which are associated with the operational definition of the "time interval between the events."

The two propositions outlined above would seem appallingly strange to a classical physicist. It must be admitted that in the application presented, the departures from the behavior expected on the basis of Newtonian mechanics are minute and certainly the measuring procedures involved could not be carried out with sufficient precision to demonstrate any inadequacy of classical ideas.

However, 800 miles per hr is only one millionth of the speed of light. As relative speeds of objects approach this limiting speed, the inadequacies of Newtonian mechanics become undeniably apparent (see the table below). It should be noted that as far as gross objects are concerned, we simply have no experience in the region of high relative speeds. To accelerate an object with a mass (at rest) of 1.0 gm to 80% of the speed of light, for example, would require the expenditure of about 45×10^6 kw-hr of energy! Actually it is doubtful if any particle more massive than a proton has ever been observed to travel at so high a relative speed.

This points up another danger, related to the one above, of which the experimenter must beware. He must not apply physical theory or laws established from one set of experiments (Newtonian mechanics derived from experiments on gross objects) to other experiments (those involving high relative speed nuclear or atomic particles) even though the extrapolation may seem very "logical." A theory has no greater scope than the experiments upon which it is based. It may be replaced at any time by a new theory, describing a wider variety of experiments, and containing the first theory as a limiting case.

Origin of Theory

The special theory had its beginnings in the unsuccessful attempts of the late nineteenth century physicists to combine Maxwell's theory of electromagnetism with classical mechanics. Such a combination seemed necessary to afford a description of the large number of experiments which can be performed in the interlying field of electrodynamics. Particularly evident troubles arose with respect to the nature of propagation of electromagnetic radiation, including light.

It is a result of classical mechanics that an observer, fixed in a certain one of a class of reference frames, cannot assign an *absolute motion* to his reference frame by any *mechanical* experiment he may perform. The reference frames involved are essentially those which are in uniform translational motion with respect to each other (inertial systems). This is sometimes called the Newtonian relativity principle. To summarize half a century of theorizing and experimentation, it seemed to some for a time as if one *could* assign an absolute motion, relative to an hypothesized "ether," to objects fixed in an inertial system by performing certain *optical* experiments. However, this point of view did not stand the test of experiment and one

was forced to conclude that it is *not* possible to assign absolute motion to an inertial system by *either* mechanical *or* optical experiments. This is the essence of the special theory of relativity, which serves to unify mechanics and electromagnetism.

The chief crucial experiments underlying the new theory are (*a*) certain observations on double stars, (*b*) measurements by Airy on the aberration of light, (*c*) Fizeau's measurement of the speed of light in a moving liquid and (*d*) the Michelson-Morley ether-drag experiments. Only the assumption that the speed of light is the same as measured by observers in all inertial systems is consistent with all of these experiments. Note that reference frames with relative accelerations have not been considered. Nor has gravitation been discussed. Careful attention to these is given in the general theory of relativity. It is perhaps to be anticipated that more unified theories will be evolved which will supplant the special and general theories (and perhaps others as well) in the sense that the former supplanted classical mechanics.

Although simply stated, the special theory has necessitated drastic revision of our ideas of space and time. It has forced us to seek operational definitions for these quantities. These are best indicated by writing down the Lorentz transformation equations for mechanics which serve to connect the operationally defined space and time coordinates (x,y,z,t) assigned by an observer to a certain event, with a corresponding set of coordinates (x',y',z',t') operationally assigned to the same event by a second observer, fixed in a coordinate system which is in uniform translatory motion with respect to the first. The event might be the sudden turning-on of a light source. For the special case in which the two sets of axes are parallel and the two systems have a relative speed v along their common x-axis, one has (*3*)

$$\begin{aligned} x' &= (x - vt)(1 - v^2/c^2)^{-\frac{1}{2}} \\ y' &= y \\ y' &= z \\ t' &= (t - vx/c^2)(1 - v^2/c^2)^{-\frac{1}{2}} \end{aligned} \qquad (1)$$

These equations contain, as a postulate basic to their derivation, the hypothesis that the speed of light c is the same for each observer. It follows from Eqs. 1 that operationally defined lengths and time intervals do indeed depend upon the relative motion of the experimenter. These equations, in the limit of $v \ll c$, reduce, as they must, to the familiar transformation laws of classical mechanics, which are, for this special case

$$\begin{aligned} x' &= x - vt \\ y' &= y \\ z' &= z \\ t' &= t \end{aligned} \qquad (2)$$

In making use of the special theory, one finds that many quantities (momentum, kinetic energy, etc.) which have been defined for the purposes of classical mechanics are no longer useful under these definitions. Momentum, for example, if defined from the relationship (classical),

$$p = mv \qquad (3)$$

where m is the mass of the particle, is not useful in special relativity, chiefly because momentum so defined is not conserved for interactions involving isolated systems, except, of course, in the limit of small relative speeds. One seeks a new definition of "momentum" such that observers in all possible inertial systems, observing the same isolated collision or disintegration would agree that the sum of the momenta of all particles involved before the event equals the sum of the momenta of all particles involved after the event. In more technical language, this implies that the law of conservation of momentum must be unchanged in form (covariant) under a Lorentz trans-

formation.* Further, the new definition must reduce to Eq. 3 in the limit $v \ll c$. As it turns out, the following definition satisfies all requirements,

$$p = mv(1 - v^2/c^2)^{-\frac{1}{2}} \qquad (4)$$

Frequently, the quantity $m(1-v^2/c^2)^{-\frac{1}{2}}$ is defined as a *relativistic mass* m', as distinguished from the *rest mass* m. This has an advantage of making the relativistic momentum expression superficially resemble Eq. 3.

As far as kinetic energy is concerned, one can, guided by classical mechanics, define it from

$$E = \int (dp/dt) \cdot dx = \int_0^p v \cdot dp$$
$$= mc^2(1 - v^2/c^2)^{-\frac{1}{2}} - mc^2$$
$$= m'c^2 - mc^2 \qquad (5)$$

In the limit of $v \ll c$, this expression reduces to the classical $\frac{1}{2}mv^2$. The term mc^2 is called the *rest energy* of a particle, the term $m'c^2$ being known as the *total energy*. The table which gives the kinetic energy at which the classical and relativistic kinetic energy expressions differ by 1.0% and by 50% for various particles, shows the importance of a relativistic treatment for electrons and mesons at quite moderate energies and for all particles at sufficiently great energies.

It can be shown that the total energy $m'c^2$ is conserved for interactions involving isolated nuclear or other systems. From the definition of total energy, this is equivalent to assuming a conservation of relativistic mass law for such interactions. In view of the relation (Eq. 5)

system total energy = Σ kinetic energy + Σ rest energy

it is seen that if the sum of the kinetic energies of the particles in an interacting system changes there must be a compensating change in the rest energies and hence in the rest masses involved. Generalizing this to include changes of energy of any sort involving an isolated system, one has the well-known mass-energy equivalence theorem

$$\Delta E = \Delta mc^2 \qquad (6)$$

The most striking verification of Eq. 6 is found in the mirror phenomena of pair production and annihilation. In the former, a gamma quantum of energy $h\nu (> 2mc^2 = 1.0$ Mev) disappears, giving rise to a positron and an electron which share between them a kinetic energy $(h\nu - 2mc^2)$ where m is the common rest mass. In the latter, a positron at rest combines with an electron at rest; the two particles vanish, and two gamma rays of energy $h\nu = mc^2$ appear. Both these phenomena are established beyond any reasonable dispute. Note that for photons the total energy is given by $h\nu$. A photon relativistic mass can be defined from

$$m' = E/c^2 = h\nu/c^2 \qquad (7)$$

if one wishes to apply the conservation of relativistic mass law to reactions involving photons (4).

Further application and verification of Eq. 6 comes from a study of exact atomic masses. The atomic mass of Li^6 for example is measured as 6.01697

Kinetic energy at which the classical kinetic energy expression fails by 1.0% and by 50%

Particle	*Relative rest mass*	$E_{1\%}$* *Mev*	$E_{50\%}$† *Mev*
Electron	1	0.0032	0.31
Meson	200	0.64	62
Proton	1900	6.1	590
Fe^{55}	55 × 1900	330	32,000

* speed for all particles is 0.11c
† speed for all particles is 0.78c

* In special relativity, all laws must be unchanged in form under a Lorentz transformation. This follows from the hypothesis that all inertial systems are equivalent as far as the performance of experiments in them is concerned. Newton's first law is covariant under either a Lorentz or a classical (Eq. 2) transformation. Newton's second law is covariant under a classical but not under a Lorentz transformation. Maxwell's equations are covariant under a Lorentz but not under a classical transformation.

mass units. Such an atom may be imagined divided, with the expenditure of a certain energy, into three free neutrons of mass 1.00893 mu each and three free hydrogen atoms of 1.008123 mu each. The sum of the mass of the six constituents is 6.05116 mu which exceeds the mass of Li^6 by 0.03419 mu. Multiplying by c^2 (written in the convenient form of 931 Mev/mu yields $\Delta E = 31.8$ Mev which is interpreted as the energy which must be added to a Li^6 atom to separate it into the above six constituents. The use of Eq. 6 in stability calculations is apparent from this example. This is a powerful tool. It is as if chemists could compute heats of formation from molecular and atomic weight data which, indeed is to be viewed as possible provided something like a million-fold increase in the precision of molecular weights be attained! Still further application of the law of conservation of total energy is associated with nuclear bombardment reactions and with radioactive decay.

In the common limiting case in which the bulk of the total energy of an isolated system is rest energy, the relativistic law of conservation of total energy becomes identified with the classical conservation of mass law and Eq. 6 becomes quantitatively unimportant. For example, if 100 cal of heat be added to a 10.0 gm copper block, raising its temperature by about 110° C, Eq. 6 would predict a mass increase for the block of only 5×10^{-6} μgm. Similarly, in the burning of carbon according to

$$C + O_2 \rightarrow CO_2$$

about 8000 cal per gram of carbon are evolved. This means that for the burning of 2.0 kg of carbon, the mass of the CO_2 formed would be less than the combined mass of C and O_2 by only 0.8 μgm.

As far as the motion of charged particles in electromagnetic fields is concerned, let us consider two common situations. If a particle of charge e and rest mass m moves from rest through a potential difference V, what will be its kinetic energy? It turns out that the expression is similar to the classical one,

$$E = eV \qquad (8)$$

except that the E of Eq. 5 must be used. This result is not trivial and requires demonstration. It is clearly applicable to computing expected ion energies from electrostatic generators.

Secondly, if a particle is observed to be moving in a circular path of radius of curvature R, the plane of the path being perpendicular to a uniform field of magnetic induction of strength B, what must be its momentum? Once more, the equations resemble the classical ones, namely

$$Bev = m'v^2/R \qquad (9)$$

or

$$p = m'v = BRe \qquad (10)$$

Motion of charged particles perpendicular to a uniform magnetic field is a very common experimental situation, occuring in synchrotrons, cyclotrons, certain beta-ray spectrometers, certain mass spectrometers, betatrons, certain cloud chamber arrangements, etc. In all of these cases, the quantities B and R may be reported as primary measurments. Even in situations in which such motion does not explicitly occur, it is often the momentum of the particle rather than its energy which is most simply handled. In beta-ray spectrometers of the magnetic lens type, for example, the momentum of the focussed electron is directly proportional to the lens current. Eq. 10 shows that the product, BR, is proportional to the relativistic momentum. Very often, it is called "momentum" although *magnetic rigidity* (only occasionally used) would seem more suitable.

Often the relationship between magnetic rigidity or momentum and kinetic energy is wanted. This is easily shown to be

$$p/e = BR = a(E^2 - bE)^{1/2} \qquad (11)$$

or conversely

$$E = -e + [e^2 + d(BR)^2]^{1/2} \quad (12)$$

in which

$$a = 1/ce = 3335.8 \text{ gauss-cm/Mev}$$
$$b = 2mc^2 = 1.0217 \text{ Mev} \quad (13)$$
$$d = (ce)^2 = 8.986 \times 10^{-8} \text{ Mev/gauss-cm}$$
$$e = mc^2 = 0.5108 \text{ Mev}$$

The numerical values above are for the common case in which the particle is an electron. Birge's 1942 values for the physical constants have been used. Eq. 11 shows that for $E \gg b$, the momentum becomes proportional to the kinetic energy. This is an easily attainable situation for electrons, in cosmic rays and elsewhere. Note that this is equivalent to assuming the rest energy negligible in comparison to the kinetic. Actually, putting $b = 0$ in Eq. 11 leads to $p = E/c$ which is the expression to be used for the momentum of a photon in applying the relativistic momentum conservation law to interactions involving photons (Compton effect).

The special theory of relativity has much to say about the time (operationally defined) which is kept by moving clocks. A very convenient moving clock is the cosmic ray meson which is known to be unstable with a mean life of about 2 μsec. This mean life has been measured in two important ways. In one method (*5*), the meson is allowed to come to rest and to decay in an absorber. By a delayed coincidence technique, the mean time interval between the entrance of a slow meson into the absorber and the emergence of its decay product (electron) from the absorber is measured. Here, no relativistic time considerations enter because the meson is at rest with respect to the observer when it decays.

A second method (*6*) for the measurement of the meson mean life involves a simple counting of cosmic ray mesons, first at the foot of a mountain and second at the top of the mountain, with an additional absorber interposed, calculated to be equivalent in mean absorbing power to the layer of air between the two stations. The counting rate at the upper station exceeds that at the lower because of the decay of some of the mesons in traversing the air column. This is a case of decay in a reference frame (the meson) moving at a large speed with respect to the earth and relativistic considerations are important. The mean life τ_0 of mesons at rest with respect to the observer is related to the mean life τ of mesons moving with speed v with respect to the observer by

$$\tau_0 = \tau(1 - v^2/c^2)^{1/2} \quad (14)$$

For a 100 Mev meson, τ_0 and τ would differ by 100%. Suffice it to say that when relativity theory is taken into account results by the two methods are in essential agreement. This agreement, in view of many uncertainties, is by no means to be viewed as a quantititative verification of this aspect of theory, the pertinent features of which have been checked by measurements of the wavelength of light emitted by moving hydrogen atoms.

In conclusion, one may summarize by saying that in nucleonics more than in any other branch of physics, special relativity is a constant and indispensable tool. Every worker in the field should have some familiarity with it both at the level of practical application of formulas and at the level of its philosophy. It is hoped that this resumé will spur the reader to seek a more detailed knowledge of the subject.

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BIBLIOGRAPHY: Counting Circuits and Secondary Emission

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THIS BIBLIOGRAPHY, the last of three parts, was prepared for the Electronics Division of Brookhaven National Laboratory. The list below includes the subjects of counter circuits and secondary emission, in addition to general references. The first two lists appeared in the December and February NUCLEONICS and covered Geiger and proportional counters, ionization chambers, electrometers, and statistics.

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NUCLEONIC EVENTS

KODAK DEVELOPS EMULSION SENSITIVE TO ELECTRONS

A new nuclear emulsion, which is said to show considerable promise for investigation of light nuclear particles, has been produced by Kodak, Ltd., Harrow, England. Using a silver halide concentration about equal to that of the gelatin (about a five-fold increase over normal concentrations), Kodak has developed a method of sensitization which results in a grain sensitivity said to be three or four times greater than that of the Ilford emulsions. The Kodak plates are not loaded and are coated for nuclear research with a 30 micron layer. The background fog is kept to a very low level.

The Kodak development is very recent and consequently not much detailed information concerning these plates is available. It is claimed, however, that they are electron sensitive. Tests have been made with (continuous) X-rays in the range of accelerating voltages from 35 kv to 100 kv. The tracks of the photo-electrons, recoil electrons, etc., are clearly distinguishable even though the scattering is considerable. The most probable number of developed grains per track is about 6 for a plate irradiated by 35 kv X-rays, rising to about double that number for 80 kv X-rays. The range of the electron tracks in the emulsion reportedly agrees with theoretical range predictions.

The fading of the latent image is said to be no more serious than for other emulsions. One test exposure showed a loss in grain count of 30–40 percent after one month's fading.

The future research on the new Kodak emulsions will be directed toward improving the grain sensitivity as a means of avoiding some of the fading difficulties. At present the minimum distinguishable track length is 15–20 m. It is hoped to better this figure by a factor of perhaps 2.

Experiments with the Kodak plates irradiated by controlled sources of monoenergetic beta rays are under way in the physics department at the University of Edinburgh. It is reported also that, in the near future, C. F. Powell of Bristol University plans to expose some of the Kodak plates, in the presence of a magnetic field, at the Jungfrau Joch, Switzerland, to get further evidence on meson masses.

ONR ISSUES REPORT ON PHYSICS RESEARCH IN SWEDEN

The Office of Naval Research, London Branch, recently made a survey of research projects in physics in Sweden. It was found that research in this country is concentrated very largely in Stockholm and in Uppsala. In Stockholm, at the Institute for Physics Research, there is a program concerned with nuclear physics and also electron microscopy. At the Technical High School, research is being conducted in solar physics as well as electronics.

The program at the Royal University in Uppsala is devoted to a study of X-rays. At the Institute for Physical Chemistry at this same university, the construction of a 100-in. cyclotron is under way.

The following are excerpts taken from the report:

The Institute for Physics Research—Professor Manne Siegbahn heads the important Institute for Physics Research of the Swedish Royal Academy

of Sciences. The buildings are markedly new and capacious, well-designed, comfortable, and in general give every evidence of having strong financial support. At present, Prof. Siegbahn has about twenty students and associates working with him.

The principle lines of research being pursued are: (1) electron microscopy, (2) nuclear physics.

Concerning the electron microscope,* little need be said beyond the fact that it operates on 50–60 kv, utilizes three lenses, and exhibits a resolving power stated to be 10 A.U. Except for the last figure, matters seem to be conventional. The microscope is being applied to a number of obvious problems, none of which are of concern here.

The chief aspect of the nuclear physics program at the moment is the development of a new 88-in. cyclotron. The present 32-in. cyclotron, furnishing 6.5-Mev deuterons in currents up to 150 μamp is in operation.† It operates with 50 kv between the dees, 25 kw dissipation, at 12 Mc per sec. The vacuum chamber, of rolled brass, is not designed to render the beam removable. Rubber gaskets are used to seal the iron cover plates. The dees are of spun copper sheet. The insulation supports are of the ceramic "calite." A filament-type ion source, supplied with 1.5-Mc per sec heating power, is used. The high-frequency tubes were, for a long time, home-made and continuously pumped, but new demountable tubes of Swedish manufacture have replaced the older ones.

The new cyclotron will be housed partly underground in a new building now under construction. It is expected to produce 30-Mev particles. Molecular pumps, as is well known, are popular in Sweden and are in general use. Their maximum speeds however are, up to now, only about 100 liters per sec, and consequently will have to be replaced by the faster oil-diffusion pumps for the new cyclotron. The new cyclotron building is designed so that there is about 10 meters between the machine and the control room, providing space for adequate and extensive shielding of the operators. The magnet for the cyclotron was expected late last year. The high-frequency tubes will be the new 100-kw tetrodes produced in England by Standard Telephone and Cables, Ltd.

The work in beta-ray spectroscopy, under the leadership of Kai Siegbahn, N. Svartholm, and N. Hole, is progressing extensively. Publications are shortly to be issued on the beta-ray spectrum of Np^{239}, U^{239}, and W.

A new beta-ray spectrograph, roughly similar to that being designed by Siday in Edinburgh (see *Newsletter* **1**, No. 2, p. 5), has been constructed by K. Sieg-

NUCLEONICS *TO PUBLISH NUCLEAR DATA TABLES*

"1947 Summary of Nuclear Data," a compilation of the results of research here and abroad during the period from August, 1946, to November, 1947, will be published next month as a dividend to subscribers of NUCLEONICS. Compiled by the Nuclear Data Committee of Clinton National Laboratory, Oak Ridge, Tenn., the special issue (extra copies of which will be available) will be part 2 of the regular April issue.

Included in the tables are data on nuclear reactions, cross sections, masses, abundances, moments, and radioactivity. This data was compiled from 34 journals, American and foreign.

* See application of this instrument in *Nature* **154**, 237 (1944); *Arkiv f. Botanik* **30B**, No. 4 (1941); *Arkiv f. Zoologi* **35A**, No. 5 (1943).

† This cyclotron is described in an article in the anual report of the Institute: H. Atterling, K. Svenska Vetenskapakademiens Årsbok for 1945.

bahn and N. Svartholm. Focussing occurs at 255 deg at a radius of 50 cm. The usable solid angle exceeds 0.1. The inhomogeneous fringing fields with cylindrical symmetry are utilized to obtain focussing in two perpendicular lines.*

The beta-ray spectrometer recently used extensively is described by K. Siegbahn in *Phil. Mag.* **37**, 162 (1946). A lens is constructed with a field convex downward in order to reduce the effect of spherical aberration. This is accomplished by closing the ends of the lens with iron disks and pole pieces suitably shaped. Holes bored in these ends permit use as a beta-ray spectrograph. The focussing coil consists of 7,200 turns on an iron cylinder of 60-cm length, of inside and outside diameters 10 and 16 cm, respectively. A Geiger tube is used as detector. The sample is introduced through a lock. This spectrometer gives, for the same resolving power, twice the intensity of Siegbahn's earlier model. In operation, about 3 percent is the best usable resolving power. Samples as small as a few hundredths of a microcurie may, in some cases, be measured.

The scope of the work on beta- and gamma-ray spectroscopy, utilizing the lens spectrograph as well as earlier instruments, can probably be best appreciated by a short bibliography of recent publications from this group.

1. K. Siegbahn, H. Slätis, On the γ Radiation from Polonium and from Lithium Bombarded with α particles, *Arkiv. f. Mat, Ast. och Fys.* **34A**, No. 15 (1947)
2. A. Johansson, Nuclear Levels in ThC′ and ThD as Studied by Means of Their γ Rays, *Arkiv. f. Mat., Ast. och Fys.*, **34A**, No. 9 (1947)
3. K. Siegbahn, The Disintegration of Mn^{56}, *Arkiv. f. Mat., Ast. och Fys.* **33A**, No. 10 (1946)
4. K. Siegbahn, The Disintegration of Cl^{38}, *ibid.*, No. 9 (1946)
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6. K. Siegbahn, H. Slätis, An Investigation of the Faint X-radiation from P^{32} and RaE, *ibid.*, No. 6 (1946)
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11. K. Siegbahn, The *K*-capture of Be^7, *Arkiv. f. Mat., Ast. och Fys.* **34B**, No. 6 (1946)
12. K. Siegbahn, A. Johansson, Coincidence Spectrometry for Disintegration Problems, *ibid.*, **34A**, No. 10 (1946)

Royal University of Uppsala—Professor A. E. Lindh is in charge of the Physics Institute at the Royal University of Uppsala, assisted by Dr. P. Ohlin. Although the department is not large, about twelve graduate students are enrolled and the facilities for research appear to be completely adequate.

Ohlin himself is engaged on a redetermination of the fundamental ratio h/e. He will use lower voltages and both tungsten and oxide cathodes to see if the value of h/e is affected by hitherto unaccounted-for vagaries in assessing the voltage distribution along the source of electrons. The question of the influence of the work function of cathode and anticathode will also be studied.

Originally† Ohlin carried out measurements with a curved crystal in the 3–5 kv region, already considerably lower than the voltages used by Dumond and by Kirkpatrick. Careful study of the isochromats have shown an inexplicable minor peak near the limit being investigated, and one of the principal objects of the new work is to study this phenomenon in more detail. A Geiger counter is used as the X-ray detector, and the voltage source is electronically regulated. As might be conjectured, the experimental apparatus is extremely well constructed in all respects. Arrangements are available for reducing the air pressure in the

* N. Svartholm, *Arkiv. f. Mat. Ast., och Fys.* **33A**, No. 24 (1946).

† P. Ohlin, An X-ray Determination of h/e, *Inaugural Dissertation*, Uppsala (1941).

spectrometer to permit isolation of the pressure effects that were discovered by Ohlin to affect significantly the accuracy of the determination.

Since much of the effort at Uppsala in the past has been in the field of X-rays, it is not surprising that large emphasis is still being placed on accurate and careful measurements in this field. One problem under way is a study of the absorption of X-rays in gases, utilizing a curved-crystal spectrometer. The gas is actually contained in the Geiger counter used as detector. No results have been forthcoming as yet.

During the war Professor Lindh and Å. Nilsson made some experiments on the *K*-absorption of argon, prompted by some inaccuracies found in previous wavelength values. The vacuum spectrograph was of high dispersion to resolve the fine structure. The absorption tube was of glass, 39-cm long, to one end of which the X-ray tube was fastened. The crystal was calcite. The dispersion was 12.92 X.U. per mm. With argon pressure of 8 mm Hg, tube voltage of 8 kv and current of 50 ma, 8 hours were required for an exposure. The reference line was the Fe $K\alpha_1$ line in the second order. The results were: (1) the wavelength of the principal absorption is 3862.88 X.U., on the average; (2) according to Fricke's results the absorption edge of argon should lie on the long wavelength side of the Fe $K\alpha_1$ line; this is not found to be the case; it is on the short wavelength side.

Another problem related to X-rays is a redetermination of e values of the x-unit determined from grating measurements. This will afford a calibration of the crystal scale with the absolute scale. The technique will be to rule a grating in such a way that both optical and X-ray lines may be studied and compared on the same plate. This research is just starting.

One of the first mass spectrometers in Sweden has been constructed at Uppsala. It is of the Mattauch type, of quite high resolution. Use is made, however, of the fact that, since oblique rays in the dispersing magnetic field lead to a kind of focussing perpendicular to the plane of symmetry of this field, enhanced intensity can be achieved.* At present, the mass resolving power is 1 part in 4000, although it is expected that soon 1 part in 10,000 will be achieved. The dispersion, however, is on the low side—about 2.4 mm per percent mass. A photographic plate is used as the detector. Homogeneous velocities of the ions are obtained by first accelerating to 10 kv and then using an electrical analyzer of 58 deg width before the beam is analyzed in the magnetic field (up to 16,000 gauss). The radius of curvature in the magnetic field can range from 9 to 22 cm, corresponding to mass ratios of 1:6. Hence practically all elements can be studied in three exposures. The mass spectrometer will be applied to research on heavy elements of all sorts, including uranium. The details of this instrument will shortly be published in the *Arkiv f. Math., Ast. och Fys.*

CARNEGIE TECH INCREASES CYCLOTRON RATING TO 350 MEV

Carnegie Institute of Technology has announced that its new synchro-cyclotron, when completed in 1950, should produce 350 Mev instead of the 250 Mev originally anticipated. The step-up in energy-producing capacity will be due mainly to improvements in design of its proposed 1,000-ton electromagnet. These facts were revealed when it was announced by Robert E. Doherty, Carnegie president, that work had begun on the recently acquired (from radio station KDKA) 60-acre site at Saxonburg, Pa.

Committees which will be responsible

* C. Reuterswärd, *Arkiv. f. Mat., Ast. och Fys.* **30A**, No. 7 (1943).

for various phases of the project are the science committee consisting of Frederick Seitz, head of the physics department, chairman; Webster N. Jones, director of the College of Engineering and Science; J. C. Warner, Dean of Graduate Studies; and Edward C. Creutz, associate professor of physics; and an advisory committee on design composed of Pittsburgh engineers. Headed by W. W. Powell of the Mesta Machine Co., the latter includes F. S. Bloom, president, Bloom Engineering Co.; H. L. Cole and R. L. Witzke of the Westinghouse Electric Corp.; Edward Crump, Crump Construction Co.; B. J. Fletcher, Aluminum Company of America; J. W. Price, Jr., Carnegie-Illinois Steel Corp.; and R. E. Noble, Mesta Machine Co.

PAPERS ON NUCLEAR STUDIES TO BE GIVEN AT IRE CONVENTION

Five papers and a symposium on nuclear studies will be part of the program of the 1948 Annual Convention of the Institute of Radio Engineers to be held March 22–25 at the Hotel Commodore in New York City.

The following papers will be presented on March 23: "Oscillator Design for the 130-inch F-M Cyclotron," E. M. Williams and H. E. DeBolt, Carnegie Institute of Technology, Pittsburg, Pa.; "An Electronic Interval Selector for the Determination of the Dead Time and Recovery Characteristics of Geiger Counters," L. Costrell, National Bureau of Standards, Washington, D. C.; "Electronic Classifying Cataloging, and Counting Devices," J. Howard Parsons, Monsanto Chemical Co., Oak Ridge, Tenn.; "Health Physics Problems in Atomic Energy," K. E. Morgan, Monsanto Chemical Co., Oak Ridge, Tenn.; and "A Selective Detector for Heavy Charged Particles," Keith Boyer, MIT, Cambridge, Mass.

Also, on March 23, a symposium on nuclear science will be held in which the panel of speakers will discuss basic problems in nuclear studies. Lawrence R. Hafstad, chairman, will deliver the opening address, "The Atomic Energy Problem and the Engineer." Three papers to be presented are "The Program of the Atomic Energy Commission," "Electronic Problems of the Atomic Energy Program," and "Biological Effects of Radiation and Consideration of Protection Problems."

NOTES ON RECENT RESEARCH AT BUREAU OF STANDARDS

The National Bureau of Standards has announced the following results of recent research:

Spectra of Tantalum—Compilation of a new list of Ta I lines based on a new series of spectrograms, has been completed (by C. C. Kiess). The list extends from 10,000 A. U. in the infrared to 2,100 A.U. in the ultraviolet and comprises, in addition to new wavelengths, revised intensity estimates, and Zeeman patterns. The list is being used for the investigation of nuclear energy levels in conjunction with the program under way at the Bureau involving the compilation and publication of all available information on nuclear energy levels.

Dosage Measurement in X-ray Therapy—Preliminary measurements (by L. S. Taylor) of the air ionization produced by the Bureau's 50 kv, 30 ma, beryllium-window tube have been proceeding satisfactorily. Intensities up to 2 million roentgens per min are indicated at a distance of one cm from the window. At the normal measuring distance of about 5 cm, it is found that ordinary ionization chambers do not function properly because of the extremely high recombination rate due to the dense ionization. Where, for ordinary intensities of the order of 100 roentgens per min, a parallel plate ionization chamber can be saturated at a field strength of about 50 volts per cm,

it has been found that at high X-ray intensities, field strengths of the order of 6,000 volts per cm are required for saturation even though the tube is only operating at about one half of its maximum output. With such high fields, corona effects become evident in the chamber. It is therefore necessary to re-design a corona-free chamber for operation at these high field strengths.

Some progress is being made along these lines but a final design has not yet been reached. This requirement for high field strength casts considerable doubt on previous work done under similar conditions in other laboratories. The Bureau is therefore attempting to devise a means whereby correction factors between the earlier measurements and the measurements under suitable field conditions can be established. Difficulty in this work was also encountered because of dielectric absorptions in the polystyrene insulators normally used in such ionization chambers. The effect of this absorption is very much amplified when the dielectric is exposed to radiation. It is, therefore, necessary either to completely shield the dielectric, reduce it to a minimum or preferably completely eliminate it from the system and at the same time use null methods of measurement.

INDUSTRIAL COMPANIES JOIN U. OF. CHICAGO RESEARCH PLAN

Westinghouse Electric Manufacturing Co. and the Aluminum Company of America have become associated with the University of Chicago in a combined program of atomic research, according to a recent announcement by Chancellor Robert M. Hutchins. These two companies have joined with the Standard Oil Co. of Indiana, Standard Oil Development Co. of New Jersey, Shell Oil Co., and Sun Oil Co., in helping to finance peacetime atomic research as industrial members of the Institute for Nuclear Studies, Institute of Metals and the Institute of Radiobiology and Biophysics.

Westinghouse is a member of all three institutes and the Aluminum Company of America has joined the Institute of Metals. The three institutes comprise a $12,000,000 research program recently launched by the University of Chicago.

According to Dr. Hutchins, members of the institutes have access to University of Chicago laboratories and scientific knowledge. University scientists participate in quarterly conferences conducted at the university to explain current progress and techniques to representatives of industrial members.

BRITISH TO CHECK RIVER WATER USED BY HARWELL PILE

Thorough precautions are being taken by the British Ministry of Supply to ensure that the water in the Thames River, England, used at the atomic energy research establishment at Harwell is returned to the river free from harmful radioactivity. These precautions have been adopted after close consultation between the Ministry of Supply and the Ministry of Health, the Metropolitan Water Board and the Thames Conservancy, and on the advice of the Medical Research Council's Research Committee on the Medical and Biological Applications of Nuclear Physics.

Principle of the precautionary measures to be taken is that a certain amount of radioactivity in drinking water can be tolerated with safety by human beings. The tolerance laid down by the Medical Research Council for the Harwell effluent is such that medical and biologic effects would be, for all practical purposes, negligible.

Roughly a million gallons of water per day will be drawn from the Thames when the Harwell establishment reaches its full stride. Not all of this water, however, will be exposed to radio-

activity. The greater part will be used for the cooling of plant and ordinary domestic requirements at the establishment. The remainder of the water will be used for research processes, some of them radioactive, and a carefully controlled separate water system will be installed to deal with it.

The most highly active portion of the water will be segregated and will not be returned to the river. The rest of the process water will be delivered to storage tanks where it will be tested by medical officers for compliance with the agreed tolerances, treated for chemical impurities and then mixed with the domestic waste water before being discharged into the pipe which takes it back to the Thames at Sutton Courtenay.

The system of treatment and examination involves several operations before the water actually passes into the six-mile length of discharge pipe.

A new weir is being constructed at the point of discharge into the Thames to mix the Harwell water turbulently with much greater quantities of river water immediately upon joining the main stream.

Regular tests of the river water will be made also at points farther down the Thames, to assure that the procedure is working properly.

AEC ISSUES PUBLICATIONS ON NUCLEAR PHYSICS

"Lecture Series in Nuclear Physics," a group of lectures given at Los Alamos in 1943 to aid in training personnel, has been published for public sale by the Atomic Energy Commission.

The publication, which was declassified in October, 1945, consists of forty-one chapters divided into six sections as follows: Introduction and Terminology by E. M. McMillan, Radioactivity by E. Segre, Neutron Physics by J. H. Williams, Two-Body Problems by C. L. Critchfield, The Statistical Theory of Nuclear Reactions by V. F. Weisskopf, and Diffusion Theory by R. F. Christy.

The price of the volume is fifty-five cents; it is available from the Superintendent of Documents, Washington 25, D. C.

The AEC has also published a document entitled "Background Material on Activity in First Year of Distribution of Pile-Produced Radioisotopes." This is available from the above address at a cost of ten cents.

AEC ESTABLISHES FELLOWSHIPS IN ATOMIC ENERGY SCIENCES

The Atomic Energy Commission has allocated approximately $2,500,000 for the establishment of two fellowship programs in sciences basic to atomic research and development, according to a recent announcement. The AEC has budgeted $1,500,000 to train qualified persons in physical sciences such as physics, chemistry, metallurgy, mathematics, geology and astrophysics; $1,000,000 has been allocated to studies in the biological and medical aspects of atomic energy.

Administration of both programs will be by the National Research Council of the National Academy of Sciences. Under this arrangement, the council will assume responsibility for circularization of colleges, institutes and universities; interview and selection of candidates; and adequate follow-up on the progress of the fellows. Announcements concerning number of fellowships to be offered, stipends, and the qualifications of candidates and conditions of the awards will be issued through the National Research Council in the near future.

Information available on the program is as follows:

Physical sciences—Two groups of fellowships are proposed, one at post-doctoral level and one at pre-doctoral. The former will normally be for a period of one or two years. Except in unusual cases, the predoctoral fellowships will

be awarded to candidates who have already successfully completed one or two years as graduate students and have been accepted as candidates for a doctor's degree. These fellowships will normally continue for a period sufficient to enable fellows to complete their research work for the doctorate.

Medicine and biology—Applicants from any branch of biology or medicine are eligible for fellowships. At present, however, candidates favored will be those who intend to follow a career of research in one of the basic biological or medical sciences, or clinical medicine or surgery, as related to the field of atomic energy. Applicants in medicine or surgery will be encouraged to lay out a program of study leading to thorough experience in a preclinical science during which they become identified with this science as such and not primarily with its application to clinical studies. Applications for immediate practical work in clinical subjects will be approved only if essential for the conduct of the basic research program. The initial fellowships will be distributed among three broad classes of candidates including Doctors of Medicine, Doctors of Philosophy in the biological sciences, and Bachelors of Science and of Arts, who will receive training in health physics. Post-doctoral fellowships will extend for a period of two years. Graduate training in health physics will extend for a period of one year or longer depending upon the qualifications of the candidate and his need or desire for additional training.

SPREAD OF SCIENTIFIC KNOWLEDGE CRITICIZED BY RUSSIAN GROUP

Complaining that current means for coordination and spread of scientific-technical information, particularly in leading trends of present day technology, were unsatisfactory, sixteen Soviet engineers and economists published an open letter in the Moscow newspaper *Trud*, appealing for the creation of a national center of scientific-technical-economic information, headquartered in the State Science Library.

Current means for dissemination of scientific information, effected mainly through the State Science Library which has two million volumes, are failing to meet the growing demands of research institutes, industry and the universities, the appeal noted, adding that the Library has recently begun micro-printing in limited editions of needed technical materials, but has not been receiving adequate support from the Ministry of Higher Education under which it operates.

Without serious support from the authorities both in the Ministry of Higher Education and in the Committee on Inventions and Discoveries attached to the USSR Council of Ministers, who should take the lead in establishing the national center, the appeal stated, serious improvement would not be forthcoming. A particular shortcoming noted was the lack of sufficient production-problem reviews and monographs on leading topics of modern research.

—*McGraw-Hill World News*

MEETINGS

American Chemical Society and Institute of Technology of University of Minnesota—Symposium on "Modern Instrumental Methods of Analysis," Minneapolis, Minn., March 22–24

Institute of Radio Engineers—Annual Convention and Radio Engineering Show, Hotel Commodore and Grand Central Palace, New York, N. Y., March 22–25

Institute of Aeronautical Sciences—Flight Propulsion Meeting, Cleveland, O., March 26

American Institute of Electrical Engineers—Great Lakes District Meeting, Des Moines, Iowa, April 1–3

American Society of Civil Engineers—Spring Meeting, Pittsburgh, Pa., April 7–9

Electrochemical Society—Columbus, O., April 14–17

American Mathematical Society—New York, N. Y. and Ann Arbor, Mich., April 16, 17

American Mathematical Society—Berkeley, Calif., April 17

American Chemical Society—113th Annual Meeting, Chicago, Ill., April 19-23

Acoustical Society of America—Washington, D. C., April 22-24

American Philosophical Society—Philadelphia, Pa., April 22-24

National Academy of Sciences—Washington, D. C., April 26-28

American Association of Petroleum Geologists—Denver, Colo., April 26-29

American Society of Medical Technologists—St. Paul, Minn., June 7-9

American Society of Medical Technologists—St. Paul, Minn., June 7-9

Pittsburgh International Conference on Surface Reactions—Mellon Institute of Industrial Research, Pittsburgh, Pa., June 7-11

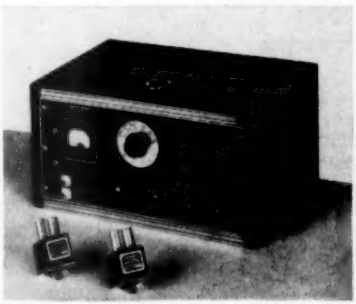
Institute of Radio Engineers—6th Annual Electron Tube Conference, Cornell University, Ithaca, N. Y., June 28, 29

National Instrument Conference and Exhibit—Convention Hall, Philadelphia, Pa., Sept. 13-17

PRODUCTS and MATERIALS

"64" SCALER

Tracerlab, Inc., 55 Oliver St., Boston 10, Mass. The "64" scaler uses the recently announced Duoscale plug-in scaling unit, which incorporates the Higinbotham circuit, to permit replacement of defective scaling circuits. A scale selector switch is provided to allow the output of any scale from 8 to 64 to be connected to the driver amplifier for the panel-mounted counting register



which is an integral part of the instrument. Six neon interpolating lights are mounted behind the clear lucite scale selector dial. Provisions are made on the back of the scaler for the connection of a standard electric stopclock such that the clock is turned off and on at precisely the same time as the scaler counting circuit.

GAMMA RADIATION METER

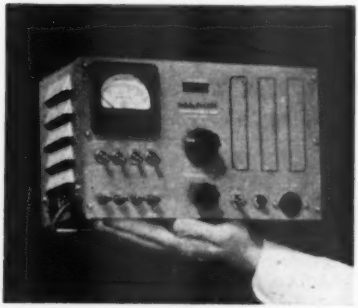
Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, O. The portable, 274A gamma-ray survey meter is of the

ionization chamber type and is claimed to combine stable operation with rugged construction. Four ranges of sensitivity are provided and the instrument is calibrated to read in roentgens with full-scale readings of 2.5, 25, 250, and 2,500 mr per hr. The case is watertight and both the meter and the ionization chamber are hermetically sealed. An eccentric range switch is

provided with a color code to give visual indication of the range at which the survey meter is set.

DECADE SCALER

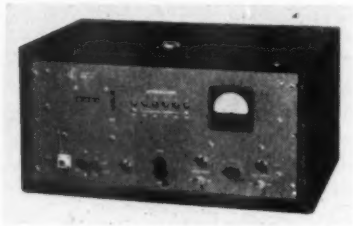
Berkeley Scientific Co., 601 Nevin Ave., Richmond, Calif. The model 1000 decade Geiger-Müller scaler weighs 11 lbs. and has the following dimensions: 11 in. × 7 in. × 5¾ in. It contains a



built-in, high-voltage (200–2500) power supply, electronic scales of 100 and 1,000, and an internal mechanical register. Contained in an enamel cabinet with a lucite panel, the unit is claimed to resolve paired pulses of 10 microsecond spacing.

SCALER

Instrument Development Laboratories, 223 W. Erie St., Chicago 10, Ill. The model 165 scaler operates on impulses from a G-M counter which actuate the built-in register once for each 64 impulses it receives. The unit has a self-contained, high-voltage supply which can be provided to give a maximum of either 1,500 or 2,500 volts. No preamplifier is required for use with the



G-M tube. The internal circuit is claimed to have an input sensitivity of 0.25 volts and a resolving time of better than 5 microseconds.

"One thing industry has got to learn is its responsibility for supporting fundamental research in our universities. It is easy to get money out of industry for a particular applied job, but . . . for fundamental theoretical research . . . it is hard to do . . . In any program for the government support of research, you have got to watch for three things . . . This research must be fundamental and possible regardless of where it leads . . . Second there must be freedom from too much coordination and control. You cannot direct an explorer, who is in a new field, where to go. He has got to find out for himself. Third, there must be no bureaucratic or political control."

—E. W. Sinnott, from an address at the 52nd Congress of American Industry, N. Y., Dec. 5, 1947

ABSTRACTS

CHEMICAL PUBLICATIONS

Radiations from uranium (239) and neptunium (239), N. Feather (Edinburgh University, Scotland), *Nature* **160,** 749 (1947). The nuclear γ radiation of $_{92}U^{239}$ has an energy of 73.2 ± 0.3 kev as determined by measurements on the line spectrum of *L*- and *M*-photoelectrons. The energy limit of the main β spectrum has a value of 1.12 Mev. These values are in agreement with previously reported values. However, the level scheme proposed by Slätis could not be substantiated, since the γ radiation of energy 870 kev indicated by this scheme could not be found by the absorption method. A second γ radiation was observed and its intensity estimated at about 0.10 per disintegration, assuming that the quantum energy was of the order of 300–600 kev. The β-ray spectrum of $_{93}Np^{239}$, determined by the absorption method, agrees with the results obtained by Slätis using the Fermi analysis.

Health physics and its control of radiation exposures at Clinton National Laboratory, K. Z. Morgan (Clinton National Laboratory, Oak Ridge, Tenn.), *Chem. Eng. News* **25,** 3794–3798 (1947). Health physics is a new branch of science devoted to the study of penetrating radiations and the prevention of radiation exposure of personnel. The tolerance level for X and gamma radiation has been set at 100 mr per day, and that for fast neutrons has been set at 20 mrep per day. The various types of counters used for different contamination measurements, and personnel monitoring instruments, are discussed. It is important that radioactive waste products be properly disposed of; all high-level radioactive waste should be stored or buried in especially selected and approved locations.

Application of filter paper partition chromatography to radioactive tracer studies, R. M. Fink, C. E. Dent, K. Fink (Univ. of Rochester, N. Y.), *Nature* **160,** 801–803 (1947). The technique of paper chromatography in conjunction with radioautography was applied to the study of the metabolic fate of compounds labeled with I^{131}. Carrier-free I^{131} was administered intravenously to each of two normal adult rats. After 24–48 hours the rats were killed and the thyroids removed and hydrolyzed. Both one and two-dimensional paper chromatograms were made with the hydrolysate, and a radioautograph made of each chromatogram. The results show definite spots of radioactivity at the positions taken by inorganic iodide and diiodotyrosine, little radioactivity at the spot corresponding to thyroxine, a diffuse background of radioactivity, and several spots of radioactivity from unidentified substances. The authors believe that with improvements in technique this method will be a valuable tool for the study of intermediate metabolism.

Origin of cosmic ray stars at sea-level, D. H. Perkins (Imperial College of Science and Technology, London), *Nature* **160,** 707–708 (1947). Experiments were carried out with Ilford nuclear research emulsions exposed on high mountains and at sea level with various absorbing materials. The ratio, *R*, of the number of single tracks to disintegration stars was found to be fairly constant irrespective of altitude. The value of *R* when materials of various atomic number were in contact with the plates was measured and compared with calculations based upon the assumption that the single tracks arise from stars produced in the material adjacent

to the emulsion. The calculated and observed values agree fairly well. The variation in the number of single tracks in plates exposed under different thicknesses of lead and paraffin was measured. Using the data from the experiments it is concluded that neither photons nor neutrons can account for more than about 10% of the stars. It is probable that the particles responsible for the stars are uncharged.

Autoradiograph technique, S. R. Pelc. (Hammersmith Hospital, London, W. 12), *Nature* **160,** 749–750 (1947). Improved resolution has been effected by a technique which comprises (1) removing stripping emulsion from its base and placing it over a slide carrying a radioactive biological section, (2) drying the emulsion-coated section and placing it in a light-proof container until adequately exposed, and (3) developing and fixing. The original section and the autoradiograph are superimposed and can be viewed simultaneously. Ilford half-tone, thin film, dry stripping emulsion was found very suitable. The exposure is about four times as great as for fast X-ray film. Sections of thyroid from rats which had been injected subcutaneously with I^{131} were used for the experiments. Iodine was concentrated in the colloid of the thyroid follicles.

Escape of thoron from thorium X salts, F. Běhounek, J. Klumpar (Radiotherapeutical Institute, Praha-Bulovka), *Nature* **160,** 640–641 (1947). It has been shown that there is no leakage of thoron from unsealed radiothorium containers when exposed in the free air. To remove the thoron from the radium-thorium salts, an appreciable difference between the pressure of the surrounding air and of the air enclosed with the salts is necessary.

Formation of uranium hydride, J. Guéron, L. Yaffe (Commissariat à l'Énergie Atomique, Paris, and National Research Council, Chalk River, Ontario), *Nature* **160,** 575 (1947). UH_3 may be formed from hydrogen and massive uranium even at room temperature. The time for complete reaction at different temperatures is $\sim$ 2 weeks, 20°; $\sim$ 1 week, 50°; 24 hr, 100°; 2 hr, 200°. When uranium which had been irradiated by a radium-beryllium source was reacted with hydrogen, it was found that there was no activity in the unreacted hydrogen, indicating that not even the rare gases formed in fission were released during formation of UH_3.

β- and γ-radiation from U^{239} and Np^{239}, H. Slätis, *Nature* **160,** 579–580 (1947). By means of absorption measurements in lead, the γ radiation from U^{239} was found to consist of two components of energies 920 and 80 kev, while the γ radiation from Np^{239} was found to consist of three components, 500, 200, and 51 kev. The β spectra were studied in a magnetic lens spectrograph. A Fermi analysis showed that the β spectrum of U^{239} is double, with the upper energy limits 2.06 and 1.12 Mev. These results lead to a disintegration scheme in which the greatest part of the β decay leads to an excited Np nucleus, while a small part leads to the ground state. A Fermi analysis of the β spectrum of Np^{239} showed that it was fourfold with the upper energy limits 1179, 676, 403 and 288 kev. The Pu^{239} nucleus seems to have six excited levels, the difference between which are 275, 227, 206, 67, 61 and 57 kev. The β decay of Np^{239} would lead mainly to the 775-kev level, while the other decays would lead to the levels 893, 502 kev and the ground state. The γ quanta would be emitted in cascade.

Photo-disintegration of the deuteron, W. M. Gibson, L. L. Green, D. L. Livesey (Cavendish Laboratory, Cambridge, England), *Nature* **160,** 534–535 (1947). The photographic plate method

was used to study the angular distribution of the emitted protons in the photo-disintegration of deuterons using 6-Mev γ-rays. The latter were produced by the bombardment of a thick target of sodium fluoride by a proton beam. The γ-rays were incident upon a series of photographic plates, the emulsions of which contained a proportion of deuterium. The exposed plates were examined and all proton tracks with a range greater than 20 microns which were entirely within the emulsions were recorded. The total number of proton tracks recorded was 213, and of these 60 occurring in the angular range $70° \leq \theta \leq 180°$ were considered to be due to the photo-disintegration process. Agreement between theoretical and experimental distributions is fairly close.

A radio-frequency ion source with high percentage yield of protons, J. G. Rutherglen, J. F. I. Cole (Univ. of Glasgow, Scotland), *Nature* **160,** 545–546 (1947). In order to obtain a high percentage of protons in discharges at pressures of the order of 10–50 microns, it is necessary that (1) the walls of the vessel in which the discharge takes place be made of clean glass, and the area of metal exposed to the discharge be kept to a minimum; and (2) the ionization density in the discharge be as high as possible. An ion source is described which gives a total focused beam current of 400 μa, of which the resolved proton current is 240 μa, the resolved diatomic ion current is 110 μa, the resolved triatomic ion current is 12 μa, and the resolved current of heavy ions is 40 μa. In general, a steely blue discharge color indicates less than 20% protons, and a bright red color indicates more than 50% protons.

Acetate metabolism in yeast, studied with isotopic carbon, S. Weinhouse, R. H. Millington (Houdry Process Corp., Marcus Hook, Pa.), *J. Am. Chem. Soc.* **69,** 3089–3093 (1947). The oxidation of carboxyl-C^{13}-tagged magnesium and barium acetate by bakers yeast was studied. The citrate and carbon dioxide which accumulated during oxidation were analyzed for C^{13} content and distribution. The results are in accord with the conception that the tricarboxylic acid cycle is a major oxidative process in yeast. An unsymmetrical C_6 acid rather than citrate is the direct participant in the cycle. Not all of the C_4 acids are formed from the cycle, but another mechanism exists for their formation from acetate. A rapid equilibrium does not exist between the intermediates in the conversion of acetate to citrate and carbon dioxide or bicarbonate.

Nuclear forces and the magnetic moment of the deuteron, H. S. W. Massey, T-M. Hu (University College, London), *Nature* **160,** 794–795 (1947). Using the method of Schwinger and Rarita, the neutron-proton interaction was studied by calculating the range assuming the following force laws: spherical well, Gaussian, Yukawa and exponential. While the results of the different methods were fairly consistent for three of the radial forms used, the Yukawa potential appeared much less satisfactory in this respect.

Some experiments with fast electrons and positrons produced by a 20-Mev betatron, W. Bosley, J. D. Craggs, W. F. Nash (Metropolitan-Vickers Electrical Co., Ltd., Manchester, England), *Nature* **160,** 790–791 (1947). Preliminary results are given of experiments on the scattering and absorption of fast electrons and positrons carried out with the betatron operating at a peak energy of about 17 Mev. Energy-loss measurements were made on electrons and positrons produced in the wall of a Wilson chamber and passing through the single lead plate used for spectrum determination, as well as through arrays of lead plates.

Meson decay and the theory of nuclear forces, J. L. Lopes (Univ. of Brazil, Rio de Janeiro), *Nature* **160,** 866–867 (1947). An attempt is made to fit the experimental evidence for light and heavy mesons, and the meson decay of mesons, into the present theories of nuclear forces. The short lifetime calculated for the decay process does not agree with Schwinger's mixed meson theory.

Primary ionization of β particles in alcohol vapor and argon, S. C. Curran, J. M. Reid (Univ. of Glasgow, Scotland), *Nature* **160,** 866 (1947). The primary ionization of β particles in mixtures of argon and ethyl alcohol vapor was investigated. Two counters were placed in a spectrograph so that all particles passing through the second counter also passed through the first. By measuring the counting rate in the second counter and the coincidence counting rate, the primary ionization in the gas of the first counter may be calculated. Using 0.42-Mev β particles, the mean values of the primary ionization were found to be 79.0 ion pairs per cm in alcohol vapor and 29.8 ion pairs per cm in argon.

A new isotope of tungsten, G. Wilkinson (Univ. of California, Berkeley), *Nature* **160,** 864–865 (1947). The tungsten fraction, isolated from a 5-mil tantalum foil which had received an 80 microampere-hours bombardment with 20-Mev deuterons, was found to have a previously unreported single radioactivity of half-life 140 $\pm$ 2 days, emitting electrons, X-rays and γ-rays. By direct measurement using thin beryllium absorbers and by resolution of an aluminum absorption curve, the electrons were found to have an energy of about 90 kev. The electromagnetic radiation has components of half-thickness 17 $\pm$ 1 mg/cm^2 aluminum, 124 $\pm$ 4 mg/cm^2 lead and 15 $\pm$ 0.4 g/cm^2 lead, corresponding, respectively, to energies of 8.7 kev, 59 kev and 1.83 Mev. The ratio of electrons to quantum radiation was determined to be: electrons: 8.7-kev ray: 59-kev ray: 1.83-Mev ray $= 2 \times 10^{-2}: 1.0 \pm 0.1: 1.0 \pm 0.2 \times 10^{-2}$. The isotope is assigned a mass of 181, and is assumed to be formed by a $(d,2n)$ reaction in tantalum. The radiations of the new isotope are compatible with the assumption of orbital electron capture in tungsten.

Evidence for the existence of new metastable elementary particles, G. D. Rochester, C. C. Butler (Univ. of Manchester, England), *Nature* **160,** 855–857 (1947). Among a large number of counter-controlled cloud-chamber photographs of penetrating showers, two were obtained which contained forked tracks of an unusual nature. The evidence indicates that one fork represents the decay of a neutral particle, the mass of which is greater than $770m_e$ and less than $1600m_e$, into the two observed charged particles. The second fork is believed to represent the disintegration of a charged particle of mass greater than $980m_e$ and less than that of a proton into an observed penetrating particle and a neutral particle.

Paper chromatography applied to the isotope derivative method of analysis, A. S. Keston, S. Udenfriend, M. Levy (New York Univ.), *J. Am. Chem. Soc.* **69,** 3151–3152 (1947). Amino acids may be determined by converting them to their p-I^{131}-phenyl sulfonyl (pipsyl) derivatives and estimating the latter by a paper chromatographic technique. A synthetic mixture of amino acids, simulating silk hydrolysates, was converted to a mixture of the pipsyl derivatives, which was taken up in ammoniacal alcohol and spread as a line on Whatman No. 1 paper. The chromatogram, which was developed with n-pentanol saturated with $2N$ ammonia, was cut into 5-mm strips

and counts taken on each strip. A diagram of counts versus strip number indicates several resolved bands. The recoveries were: glutamic acid 104%, serine 91%, glycine 100%, alanine 100%. By adding derivatives before chromatography, estimates may be made independent of complete resolution of bands.

. . . I. W. RUDERMAN

LIFE SCIENCE PUBLICATIONS

The urinary excretion of radioiodine in various thyroid states, F. Keating, Jr., M. Power, J. Berkson, S. Haines (Divisions of Medicine, Biochemistry, Biometry, Medical Statistics, Mayo Clinic, Rochester, Minn.), *J. Clin. Invest.* **26,** 1138–1151 (1947). Urinary excretion of radioiodine following oral administration was studied in euthyroid, hypothyroid, hyperthyroid and normal patients. The following quantities were obtained upon mathematical analysis of the urinary excretion: (1) the renal fraction (fraction of radioiodine excreted primarily in the urine); (2) the disappearance rate (the proportional rate of disappearance of I^{131} from the blood); (3) renal excretion rate (the proportional rate of excretion into the urine); and (4) the collection rate (the proportional rate of disappearance into other sites than the kidneys). The last value is an index of the thyroid-collection rate. The disappearance rate upon renal excretion analysis was found to agree fairly closely with measurements made from blood samples directly.

The renal fraction is greater than normal in hypothyroid patients and is less than normal in hyperthyroid patients. The disappearance rate was less than normal in hypothyroid cases and markedly greater than normal in hyperthyroid cases. No significant differences were observed in the mean renal excretion rates of the groups studied. Collection rates were very much less than normal in hypothyroid cases and were an average of 6 times the normal in hyperthyroid patients. Significance and limitations of this method are discussed.

Lack of effect of secondary liver extract (No. 55) on absorption of radioactive iron, P. Hahn, C. Sheppard, E. Carothers (Dept. of Biochemistry, Vanderbilt Univ. Medical School, Nashville, Tenn.), *Proc. Soc. Exp. Biol. Med.* **66,** 173–175 (1947). Radioactive iron, Fe^{59}, was fed with and without liver extract supplements to a group of normal adult women and to a patient with iron deficiency resulting from multiple acute and chronic hemorrhages. No obvious differences were observed in the absorption and utilization of iron when it was administered alone or in conjunction with the liver fraction. It is believed that the "summation response" described by Robscheit-Robbins and others is apparently not related to the effect of the secondary liver extract on absorption of iron in the gastrointestinal tract.

Urinary excretion of radioactive iodine, I^{131}, in a case of severe hyperthyroidism, K. Stenstrom, J. Marvin (Dept. of Radiology and Physical Therapy, Univ. of Minnesota Medical School, Minneapolis), *Proc. Soc. Exp. Biol. Med.* **66,** 47–49 (1947). Relatively large doses of radioactive iodine were administered to a patient with severe hyperthyroidism. After urinary excretion of I^{131} had reached a low level, stable iodine, in the form of Lugol's solution, was administered. This resulted in a pronounced increase of radioiodine excretion lasting some 48 hours after discontinuing stable iodine.

Fatty acid metabolism VI. Conversion of acetoacetate to citrate in animal tissues, studied with isotopic carbon, N. Floyd, G. Medes, S. Weinhouse (Lankenau Hospital Research Inst.,

Philadelphia; Houdry Process Corp., Marcus Hook, Pa.), *J. Biol. Chem.* **171,** 633–638 (1947). Acetoacetate tagged in the beta and carboxyl positions with C^{13} was incubated anaerobically with kidney tissue and aerobically with brain and muscle tissue. The citric acid formed in each case had a large isotope concentration in the primary carboxyl positions and a small excess in the tertiary carboxyl position. The aerobic metabolism of normal acetoacetate in the presence of isotopic bicarbonate resulted in isotope accumulation in the tertiary carboxyl of citric acid.

Variations in the isotope content of the primary carboxyls is believed to indicate that citrate is formed partially from acetoacetate carbon and partly from substrate or oxalacetate. It is suggested that both types of citrate result from the same reaction, i.e., the isotopic citrate by condensation of oxalacetate with isotopic acetyl groups from the added acetoacetate and the nonisotopic citrate by condensation of oxalacetate with nonisotopic endogenously formed acetyl groups. The presence of itosope in the tertiary citrate carboxyl is assumed to originate from CO_2 formed from α-ketoglutarate carboxylation.

A method of determining the site of retention of aerosols within the respiratory tract of man by the use of radioactive sodium, T. Talbot, Jr., E. Quimby, A. Barach (R. D. Evans Memorial and Massachusetts Memorial Hospitals, Boston; College of Physicians and Surgeons, Columbia Univ., N. Y.), *Am. J. Med. Sci.* **214,** 585–592 (1947). A preliminary report describing a method of measuring the deposition of aerosols within the respiratory tract using radioactive sodium. Physiologic solutions containing radioactive sodium were generated into aerosols by glass nebulizers. Subjects inhaled the aerosol under predetermined conditions and went immediately to a nearby room where measurements of the activity of various parts of the chest wall were taken with a Geiger counter. The total aerosol retained can be determined by a simple calculation. The method may be used to evaluate the efficiency of nebulizing methods of various therapeutic substances.

Effects of radiotoxic dosages of I^{131} upon thyroid and contiguous tissues in mice, A. Gorbman (Barnard College, Columbia Univ., N. Y.), *Proc. Soc. Exp. Biol. Med.* **66,** 212–213 (1947). I^{131} dosages of 3 to 50 millicuries per kilogram were given to young mice along with a normal diet. Complete thyroid destruction occurred within a few days upon administration of the higher dosages. With the administration of lower dosages, some thyroidal epithelium in the isthmus and cranial apex of the thyroid survived for as long as 120 days, but the parathyroids were lost. Lesions occurred in the tracheal epithelium with all dosages, and in the recurrent laryngeal nerve with the higher dosages.

Fixation of isotopic nitrogen by excised nodules, H. Machata, R. Burris, P. Wilson (Depts. of Agricultural Bacteriology and Biochemistry, Univ. of Wisconsin, Madison), *J. Biol. Chem.* **171,** 605–609 (1947). Attempts to show nitrogen fixation by nodules excised from leguminous plants by increasing the concentration of possible intermediates were inconclusive. From results of 5 years of experimentation involving isotopes it is concluded that unequivocal evidence of fixation is lacking. It is suggested that the inconsistent positive results obtained in this experiment and previous ones are due to inadequate bacteriological control. It is thus possible that the agent responsible for fixation in the symbiotic system has not yet been precisely defined.

The effects of triphosphopyridine nucleotide and of adenosine triphosphate on pigeon liver oxalacetic carboxylase, B. Vennesland, E. Evans, Jr., K. Altman (Dept. of Biochemistry, Univ. of Chicago), *J. Biol. Chem.* **171,** 675–686 (1947). ATP caused a slight inhibition of the decarboxylation of oxalacetic acid by oxalacetic carboxylase from pigeon liver. TPN markedly stimulated the reaction. The exchange reaction between $C^{14}O_2$ and the β-carboxyl carbon of oxalacetic acid was stimulated by ATP but not by TPN. The significance of these findings in relation to the mechanism of CO_2 fixation in dicarboxylic acids is discussed.

Colloidal gold containing the radioactive isotope Au^{198} in the selective internal radiation therapy of diseases of the lymphoid system, G. Sheppard, J. Goodell, P. Hahn (Dept. of Biochemistry, Vanderbilt Univ. School of Medicine, Nashville, Tenn.), *J. Lab. Clin. Med.* **32,** 1437–1441 (1947). Radioactive gold, Au^{198}, has an ideal half-life of 2.73 days and good radiation characteristics. It can be obtained at relatively low cost and is easily prepared in the form of stable colloids. No toxic effects were encountered. The technique for preparation, dosage measurement and administration are described.

Direct infiltration of radioactive isotopes as a means of delivering ionizing radiation to discrete tissues, P. Hahn, J. Goodell, C. Sheppard, R. Cannon, H. Francis (Vanderbilt Univ. School of Medicine, Nashville, Tenn.), *J. Lab. Clin. Med.* **32,** 1442–1453 (1947). Selective radiation of tumor tissue was obtained using colloidal sols of radioactive gold. The gold particles remain *in situ* probably because of their insolubility in bodily fluids. Diffuse radiation is thus possible at any desired level of tissue ionization. The colloid may be infiltrated into tissues inaccessible to X-ray and radium therapy. Should vascularity or cell structure of a tissue preclude the retention of injected solutions, the use of the cauterizing properties of $AgNO_3$ containing the isotope Ag^{111} is recommended.

. . . BERNARD KANNER

PHYSICAL PUBLICATIONS

Proton-proton scattering at 14.5 Mev, R. Wilson, E. Lofgren, J. Richardson, *et al.* (Harvard Univ., Univ. of California at Berkeley; Case Inst. of Tech.), *Phys. Rev.* **72,** 1131–1138 (1947). With a deflected beam of 14.5-Mev protons from the 37-inch Berkeley cyclotron, the scattering of protons by protons at this energy was investigated. The scattering foil was of nylon; a defining counter was used to measure differential scattering cross sections, and a monitor counter placed at the correct angle to register proton recoils. Normalization was accomplished by integrating the proton beam with a Faraday cage. Accuracy is about 10%. The results show P wave scattering enters at these energies. Theoretical curves are plotted for both S wave plus P repulsive and plus P attractive, and for S wave alone. The curve for the first seems to agree best with the experimental results at small angles. Assumed depth of the square well of the theoretical curves is 10.5 Mev, and width is e^2/mc^2.

On the interaction between neutrons and electrons, E. Fermi, L. Marshall (Univ. of Chicago, Ill.), *Phys. Rev.* **72,** 1139–1146 (1947). A short-range electric field interaction between the neutron and electron, such as would be expected if the neutron spent part of the time (about 20%) as a proton shielded by a negative meson cloud, would produce an asymmetry in the scattering of thermal neutrons by atoms in the center of gravity system. Xenon was used as the scattering gas to avoid

asymmetry due to paramagnetism or interference effects; corrections were made for thermal agitation of the atoms, including a geometrical correction. The interaction corresponding to the asymmetry observed has an absolute value of 5,000 ev or less, being −300 ev but having an error of 5,000 ev A meson theory calculation given has the result 12,000 ev.

Scattering of slow neutrons by ortho- and parahydrogen, R. Sutton, E. Anderson, T. Hall, *et al.* (Los Alamos Scientific Lab., N. Mex.), *Phys. Rev.* **72,** 1147–1156 (1947). The scattering of slow neutrons by ortho- and parahydrogen at 20° K was investigated for neutron energies from 0.0008 to 0.0025 ev. Two samples were used, one of 99.9% para- and 0.1% orthohydrogen, the other of normal hydrogen (75% ortho, 25% para); from these two cross sections, those of ortho- and parahydrogen were calculated. The energy dependence of these two cross sections are a function of the cross section of neutron scattering on free protons, and the results obtained agree best with a value 19.7 barns for free protons, and a range of 1.54×10^{-13} cm. Results also indicate neutron spin of ½ rather than ⅜ and virtual singlet state of the deuteron.

Search for positron-electron branching in certain beta emitting isotopes, W. Barber (Univ. of California, Berkeley), *Phys. Rev.* **72,** 1156–1159 (1947). The presence of both positrons and electrons as decay products of certain nuclei was investigated by using a 270° arc brass chamber with source and counter at opposite ends, placed between the poles of a magnet. (By reversing the field direction, particles of opposite charge were counted.) Upper limits for positron-electron ratios were found for fourteen radioactive isotopes, although only Br^{80} was definitely found to be a positron emitter, the others also showed stable isobars of $Z + 1$ and $Z - 1$. The reason is apparently that W_0 for electrons is (in these nonpositron emitters) twice that for positrons; in this case the ratio is $\frac{1}{500}$, or less, below the observed upper limit.

New barium and cesium isotopes: 12.0d Ba^{131}, 10.2d Cs^{131}, and long-lived Ba^{133}, S. Katcoff (Argonne National Laboratory, Chicago), *Phys. Rev.* **72,** 1160–1164 (1947). By neutron activation of Ba, a chain of radioactive Cs and Ba nuclei of weight 131 is formed. Decay products, lifetimes, and nature and energy of emitted rays, are given.

Coincidence measurements. Part I. Beta spectra, M. Wiedenbeck, K. Chu, (Univ. of Michigan, Ann Arbor), *Phys. Rev.* **72,** 1164–1170 (1947). The coincidence ratio (ratio of beta-gamma coincidences to betas) was investigated for simple and complex spectra involving no internal conversion, and for simple spectra followed by converted gamma radiation. The simplicity or complexity of a beta spectrum may be determined to some extent by the constancy of the coincidence rate as a function of absorber thickness. The theoretical results are applied to several beta-active isotopes.

Coincidence Measurements. Part II. Internal conversion, M. Wiedenbeck, K. Chu, (Univ. of Michigan, Ann Arbor), *Phys. Rev.* **72,** 1171–1175 (1947). Calculation of the conversion coefficient has usually been done by comparing the area under the excess peak on a beta spectrum with that under the entire spectrum. Coincidence ratios between beta rays and gamma rays (some of the betas coming from conversion of gammas) allow a more precise measurement. For complex beta spectra, a knowledge of the branching ratio is necessary if the method is to be applied.

A photographic apparatus for angular-distribution measurements, S. Rubin

(California Inst. of Tech., Pasadena), *Phys. Rev.* **72,** 1176–1186 (1947). A scattering camera is described that can measure the angular distribution of heavy charged particles emitted in nuclear reactions. It consists of a chamber containing a thin solid target (to give maximum intensity for given energy and angle resolution) and a single photographic plate sensitized for heavy particle detection. Various reactions involving alpha particles from disintegration by protons (obtained from an electrostatic generator) and resonance scattering in the region of proton-gamma reactions have been studied. High resolution is obtained.

Relation of frequency of occurrence of small cosmic-ray bursts to areas of sun spots and other variables, J. Broxon (Univ. of Colorado, Boulder), *Phys. Rev.* **72,** 1187–1196 (1947). The rate of ionization bursts in a heavily shielded chamber was investigated, only bursts of certain ionization being recorded. Some positive correlation but no definite connection between burst frequency and ionization amount was found. Pulses in the burst frequency associated with the negative primary pulses in the sunspot area were found, approximately in phase opposition. Higher barometric pressure produced a decrease in burst frequency of about 3% per mm Hg.

Gamma-rays from the alpha-particle bombardment of Na, Mg, Al, Si, P, S, E. Pollard, D. Alburger (Yale Univ., New Haven, Conn.), *Phys. Rev.* **72,** 1196–1201 (1947). The Q (nuclear energy change) values for various (p,p) and (α,p) reactions were obtained by observation of the groups of protons given off. By surrounding the counter with lead absorbers the absorption curves for emitted gamma rays were obtained. Gamma-ray energies also were obtained by coincidence measurements made on Compton recoil electrons. In some cases more than one component of radiation was observed. The gamma rays may be due to capture, inelastic capture, (α,n) reaction, or (α,p) reaction. Reasoning about the energies involved indicates that the last is the most likely case. Excited states of various nuclei were assigned to the various radiations.

Internally converted radiation from europium, hafnium, and osmium, J. Cork, R. Shreffler, C. Fowler (Univ. of Michigan, Ann Arbor), *Phys. Rev.* **72,** 1209–1211 (1947). The energies of gamma radiations emitted by these isotopes were determined by internal conversion electrons as measured with a semicircular focusing spectrometer, along with absorption measurements. The following are the energies: europium (154)—122, 343, 408, and 1,230 kev; hafnium (181)—132, 345, 479, and 600 kev; osmium (193)—129 kev. In some cases the ejection of photoelectrons in the parent atoms by unconverted gamma radiation was of comparable magnitude with the production of electrons by internal conversion in the relatively few decaying nuclei.

A phase-shift analysis of the scattering of protons by deuterons, C. L. Critchfield (Los Alamos Scientific Lab., N. Mex.), *Phys. Rev.* **73,** 1–6 (1948). The angular distribution of protons scattered by deuterium gas has been determined. This paper calculates the phase shifts in the wave functions corresponding to S waves and P waves. The experimental results used were those in the range of 1.5 to 3.5 Mev obtained at Los Alamos. Results for p-d results are similar to those for n-d results except for a much stronger refraction of the P wave. Strong scattering near 180° is not itself evidence for exchange forces, a changing of the proton being possible. Ordinary forces are definitely ruled out, but there is a deviation from the results obtained on the usual

assumption of central exchange forces. The energies investigated require inclusion of the D wave for a complete explanation.

Proton-gamma-ray coincidence counting with cyclotron bombardment, B. Benson (Yale Univ., New Haven, Conn.), *Phys. Rev.* **73,** 7–15 (1948). Since (α,p) and (d,p) reactions often leave the residual nucleus in an exeited state, coincidence measurements on the protons and the gamma rays emitted should give information on nuclear energy levels. Thin targets were bombarded with particles from a cyclotron, and gamma rays and protons were detected by proportional counters. The pulses were amplified and mixed in a coincidence circuit. Proportional counters were used because of their ability to lessen time lag uncertainty (allowing use of fast circuits), provide fast recovery time, and permit setting of the counting level so that only protons near the end of their range are counted. The latter allowed for investigation of different groups of protons. The reaction $Al^{27}(\alpha,p)Si^{30}$ was investigated. Various groups of protons were found, and the Q values calculated.

The limits of beta-stability, T. Kohman (Univ. of Chicago), *Phys. Rev.* **73,** 16–21 (1948). The nuclei which are beta-stable are plotted so as to indicate the charge of maximum stability (odd mass number) or the limits for nuclei of even mass and charge. The liquid-drop model was used to obtain the graph. Possibilities of finding undetected activities or undetected stable nuclei are discussed.

The (H^3,p) reaction in Rh and Co and probable evidence of the di-neutron, D. Kundu, M. Pool (Ohio State Univ., Columbus), *Phys. Rev.* **73,** 22–26 (1948). Two neutrons have been introduced into Rh and Co nuclei by bombardment with tritium. The tritium was produced by deuteron bombardment of Be. This resulted in extraneous activities due to the presence of deuterons, neutrons, etc. However, in the cases studied, the He^3 activity was sufficiently clear to be investigated. That the activity is actually due to the reactions $Rh^{103}(H^3,p)Rh^{105}$ and $Co^{59}(H^3,p)Co^{61}$ was tested by the decay curves. An Oppenheimer-Phillips (polarization) process seemed plausible. Changing the energy of the H^3 nuclei did not greatly affect the activity, which suggested the O-P process rather than the formation of a compound nucleus (Condon-Gamow-Gurney).

Under these circumstances (the proton being repelled by the heavy nuclear charge), the two neutrons may be captured as a unit, since they are held together in the H^3 and there is no specific reason for them to be separated. This would mean that the di-neuton $({}_0n^2)$ exists for the short time between the polarization of the H^3 nucleus and the capture of the di-neutron.

Penetrating showers in lead, W. Fretter (Univ. of California, Berkeley), *Phys. Rev.* **73,** 41–46 (1948). Showers of penetrating particles have been observed in a cloud chamber. The various particles may be distinguished; electrons may make cascade showers in lead if their energy is high; protons and mesons may be distinguished by ionizing power if near the end of their range, and protons of high energy may make meson showers. The cloud chamber was 16 in. diameter, 9 in. deep, and contained eight lead plates ½-in. thick and 8 in. wide. Coincidence counters were used to select showers. No penetrating particles were observed to be produced in an air shower by electronic radiation. Some penetrating particles were seen to create an electron shower which penetrated two plates (probably electron showers created by gammas

given off in turn by mesons). Over fifty pictures showing production of penetrating particles were obtained. They show a high angular deviation. Many showers were created by ionizing penetrating particles. Other penetrating particles were produced in varying numbers, according to the energy involved, along with the electronic radiation (which was often of energy high enough to produce electronic showers). The electrons absorbed enough energy from the primary radiation to account for Auger showers.

Attempts to detect the emission of secondary charged particles in the fission of U^{235} by slow neutrons, J. Cassels, N. Feather, *et al.*, *Proc. Roy. Soc.* (London) **191,** 428–441 (1947). Coincidence between two counters, one detecting only fission fragments, the other both fission fragments and lighter particles (alphas, protons, etc.) was employed. Neutrons incident on uranium oxide produced the fissions. The average number of light charged particles per fission can be calculated from the coincidence rate if there is no delay in their emission and if the variation in rise time of the counters is negligible (from $C/F = 2Pt + -\eta\epsilon$ where C is the coincidence rate, F the fission fragment rate counted, P the rate of light particles counted, t the resolving time of the coincidence circuit, and $\eta\epsilon$ the detection efficiency for light particles, calculated from the solid angle subtended at the detector by the uranium film). An upper limit on the number of alpha particles per fission is given at about (1 ± 0.5) in thirty cases. (A more accurate value was obtained at Los Alamos).

Extensive penetrating cosmic ray showers, D. Broadbent, L. Janossy (Univ. of Manchester, England), *Proc. Roy. Soc.* (London) **161,** 517–523 (1947). The density distribution of the showers was obtained by varying the distance between two trays of counters (one of which, the moving one, contained both shielded and unshielded counters), and measuring the coincidence rate. The distribution was found to be $Ax^{-0.5}$ (where x is the number of particles per square meter). Increasing the distance between the two trays from 0.5 meters to 9 meters decreased the coincidence only slightly, with either shielded or unshielded counters. This led to the conclusion that the density of penetrating and soft radiation in the shower must vary in approximately the same fashion with distance over the area of the shower. The frequencies and areas of the showers are given.

Nuclear magnetic moments, R. Latham (Cavendish Laboratory, Cambridge, England), *Proc. Phys. Soc.* (London) **59,** 972–978 (1947). An empirical regularity in behavior of nuclear magnetic moments as a function of charge and spin is pointed out, and the various regions of spin and charge investigated. The nuclei of spin zero have their magnetic moments lying on one of two curves, *which* one apparently depending on whether $c\sqrt{Z}$ (c is a constant; Z is the nuclear charge) is nearer to an odd or even integer.

The dynamics of nuclear reactions, C. Mandeville, *J. Franklin Inst.* **244,** 385–400 (1947). This is a discussion of the distribution of emergent particles in nuclear reactions, given in the usual fashion, on the basis of conservation of energy and momentum. The transition from laboratory to center of gravity system and back is explained in a detailed manner, with n-p scattering used as an example.

Straggling in range and angle as well as that due to target thickness is also investigated. The formulae resulting are furnished in concise and useful form for evaluating data.

Remarques sur la theorie du noyau, L. Bloch, *J. phys. radium* **8,** 161–164

(1947). The theory of nuclear forces is carried out using a complete analogy between the electromagnetic and meson fields. This leads to the vector meson form of the theory, simplifying it considerably and eliminating the difficulties due to noncentral forces, but is, however, confined to the classical region.

Nouveaux modes de fission de l'uranium, tripartition et quadripartition, Tsien, Ho, Chastel, Vigneron, *J. phys. radium*, **8**, 165–178 (1947). Photographic plates were used to show ternary and quaternary fission of U^{235}. Emitted in ternary fission are two heavy particles and one of mass less than 10 (a.m.u.) and range up to 45 cm. The latter is emitted preferentially in a direction perpendicular to the paths of the heavy particles. The light particle shows a mass distribution curve with a maximum at about 4. The errors in mass determination are such that it may always be an alpha particle. Ternary fission occurs only about three times in a thousand fissions.

Quarternary fission gives four particles, all of mass greater than twenty a.m.u., and occurs with a frequency of about twice in ten thousand fissions. U^{238} fission has been observed only in binary form, except for a short-range light particle occurring sometimes in ternary fission.

Radioactivity and granular composition of soil, G. Sizoo, P. Hoogteijling, *Physica* **13**, 517–528 (1947). Radioactivity of samples from the Zuiderzee was found to increase regularly with the percentage of finely divided material and increase surface area per unit volume of the mineral part. It is suggested that the correlation may be related to a preference of certain minerals for small grain size.

Radioactivity of the bottom of the Ijselmeer (Zuiderzee), G. Sizoo, P. Hoogteijling, *Physica* **13**, 561–570 (1947). A relation of radioactivity to the geologic age and character of the various layers is explained less on the basis of a radium-uranium ratio, at the time of deposit of the sediment investigated, than on the basis of radioactive equilibrium value.

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JAMES H. McGRAW, founder of the McGraw-Hill Publishing Company, and for many years its guiding light, died at the age of 88 on February 21.

Deserting a career of teaching, Mr. McGraw never left the field of technical publishing after he entered it in 1884 as a subscription salesman for the "American Journal of Railway Appliances." He soon became a publisher in his own right and by acquiring periodicals and by building up others in many industrial fields within the house, the McGraw-Hill Publishing Company now has 26 national and 8 international journals. A subsidiary, the McGraw-Hill Book Company with a list of some 2400 active titles covers practically all branches of pure and applied science as well as economics, business and social science.

The tradition of high standards in technical publishing built up by Mr. McGraw is carried on by his four sons, James H. Jr., president and chairman of the Board; Harold W., vice-president in charge of the McGraw-Hill Building in New York; Curtis W., senior vice-president and treasurer, and Donald C., vice-president in charge of manufacturing, and by the many editors and publishers trained in Mr. McGraw's ideals.